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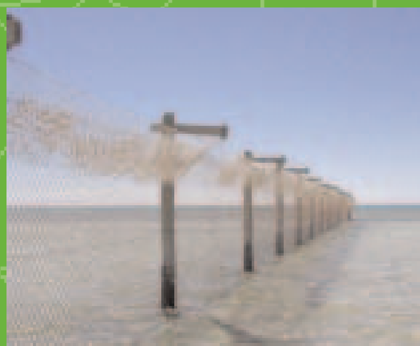
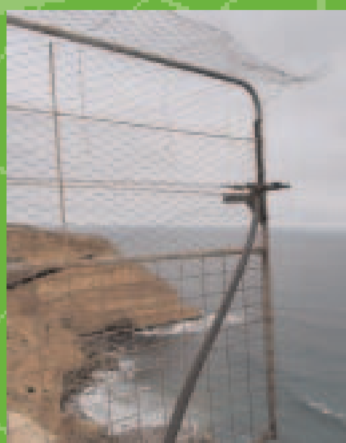
Cost Effective Feral Animal Exclusion Fencing for Areas of High Conservation Value in Australia





State Government Victoria

Department of Sustainability and Environment

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Cost Effective Feral Animal Exclusion Fencing for Areas of High Conservation Value in Australia

A report for the:

Australian Government

The Department of the Environment and Heritage

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Cost Effective Feral Animal Exclusion Fencing for Areas of High Conservation Value in Australia
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Cover photos: (anticlockwise from top left) A Gate at the Little Desert Malleefowl Sanctuary (Vic.), the fence at the Living Desert Wildlife Park (NSW), a malleefowl road-sign in NW Victoria, the cliff edge of the Venus Bay Conservation Park fence (SA), flourishing flora within the Arid Recovery Project enclosure (SA), a bettong road-sign within the Venus Bay Conservation Park, and the seaward end of the Peron Peninsula fence (WA; photo by C. Sims, CALM, WA). All photos but the last were taken by Kirstin Long.

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Executive summary and recommendations

Introduced feral animals in Australia pose a serious risk to native flora and fauna communities. The Department of the Environment and Heritage recognises in particular the impacts of European red foxes (*Vulpes vulpes*), feral cats (*Felis catus*), feral goats (*Capra hircus*), feral pigs (*Sus scrofa*) and feral rabbits (*Oryctolagus cuniculus*) as key threatening processes (*Environment Protection and Biodiversity Conservation Act (EPBC) 1999*). Exclusion fencing is increasingly being used as a tool to protect areas of high conservation value from the threats posed by vertebrate pest species. A myriad of fence designs exist for this purposes and there are currently few published guidelines available to advise conservation managers on the factors that need to be considered when assessing exclusion fence designs and when planning a fence's alignment, construction and maintenance. Coman and McCutchan (1994) conducted a comprehensive review of fox and feral cat exclusion fencing in Australia. This current document expands on Coman and McCutchan's report by updating the available information on fox and cat exclusion fencing and including reviews of fences designed to exclude the other three mentioned species. Given the history of dingo (*Canis lupus dingo*) exclusion fencing in Australia (McKnight 1969) a review of these fences is also included.

There are a considerable number of native species that would potentially benefit from the provision of an enclosure free of feral predators or competitors. However, exclusion fencing is expensive to construct and can be time-consuming to monitor and maintain. Consequently, it is necessary to establish whether exclusion fencing is necessary and can feasibly achieve the desired outcomes, and whether it is a cost-effective management tool that can be adequately resourced.

It is generally understood that no fence is likely to be 100% effective 100% of the time. In accordance with this 70% of the 20 fence managers surveyed felt that their fence was sufficiently effective despite most being breached occasionally by feral animals (only three fences reported no known breaches). To maximise the effectiveness of a fence, lethal feral animal control programs are often conducted in the surrounding buffer area to reduce the frequency with which the fence is challenged.

There is considerable variation in combined fox, feral cat and feral rabbit exclusion fence designs and in fences designed to exclude dingoes. Conversely, fences designed solely to exclude either feral goats, feral pigs or feral rabbits varied little. Given the limited experimental testing of exclusion fences that has been undertaken in Australia, it is not possible to provide an assessment of the relative effectiveness of the existing fence designs. However, it is possible to make recommendations about the minimum design specifications required for each of the targeted species based on the measured effectiveness of those designs that have been tested, the effectiveness of fences in situ, as observed by field personnel, combined with knowledge of the relevant physical capabilities and behavioural responses of the feral species.

The primary determinant of the effectiveness of any exclusion fence relates to its ability to act as a significant physical barrier. This is usually achieved with the use of wire netting or prefabricated fencing. Electric wires are commonly used to improve the effectiveness of this barrier but, on their own, rarely provide a sufficient deterrent to feral animals unless they are closely spaced so that they form a physical as well as an electrical barrier. The insulative nature of animal fur and the high resistance of dry Australian soils means that the spacing between electric wires and earthed components of a fence is critical if a shock is to be delivered to animals contacting the fence. The severity of this shock is important in determining the animal's subsequent response to the fence.

The base of a fence and corners receive the greatest attention from feral animals and consequently minor flaws in these will be readily exploited. Gates, waterway crossings and the seaward ends of fences are often weak points that are exploited by feral animals. The number of gates and waterway crossings in a fence should be minimised and care is required to ensure these features function effectively and yet still form an adequate barrier to the movement of feral animals.

Most fence managers indicated that native animals had been injured or killed in their exclusion fence. However, in all cases this occurred infrequently and is not considered to constitute a serious impact on resident fauna populations. In most cases these injuries and deaths were unavoidable, but solutions do exist to reduce impacts on some species, and also for reducing the damage they may cause to fences. Fences that restrict the dispersal of some native wildlife may prove problematic if one or more species overpopulate the enclosure.

For a fence to remain effective it must be regularly inspected and maintained. The type and level of maintenance required will vary according to the fence design, construction, and features of the local environment. Maintenance requirements will be minimised if the fence is meticulously constructed with high quality materials. Ideally, the area enclosed by the fence should also be periodically monitored for feral animal incursions.

The paucity of experimental testing that has been undertaken on feral animal exclusion fences means there is an incomplete knowledge of the physical capabilities of the targeted pest species at breaching given fence designs. Consequently it is not always possible to identify if a fence design is going to prove inadequate or over-engineered in a given environment. Filling these knowledge gaps would allow optimal, cost-effective fence designs to be determined.

1 Introduction

Through the Natural Heritage Trust, The Department of the Environment and Heritage is working to develop and implement coordinated actions to reduce damage caused by feral animals to the natural environment and primary production. Feral animals are thought to be responsible for the loss and decline of a wide range of native species. The *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) recognises, among others, the following key processes as threats to Australia's native species and/or communities:

- Predation by the European red fox
- Predation by feral cats
- Competition and land degradation by feral goats
- Competition and land degradation by feral rabbits, and
- Predation, habitat degradation, competition and disease transmission by feral pigs

Both State and Australian governments annually commit significant funds to manage or control the impact these vertebrate pests have on our environment. Control strategies include poison baiting, shooting, trapping, den/burrow fumigation, the release of biological control agents and exclusion fencing. Exclusion fencing was first used on a large scale in Australia to try and halt the spread of the European rabbit in the 1860s and 1870s, and soon after to exclude dingoes (*Canis lupus dingo)* from pastoral areas (McKnight 1969). This history of extensive exclusion fencing is unique to Australia and has been attributed to the relatively flat terrain and sparse vegetation across much of the country, which makes fencing feasible, as well as the pattern of differential land use, that made the exclusion of 'vermin' to the less inhabited interior of the continent a favourable concept (McKnight 1969).

Exclusion fencing is being increasingly used to protect areas of high conservation value or to create 'islands' of protected habitat for native fauna. It has proven a particularly valuable tool in aiding the reintroduction of threatened species to areas from which they have been previously eliminated by threatening processes, including the predatory and competitive impacts of feral animals (e.g. Dufty et al.1994, Gibson *et al*.1994, Short *et al*. 1994, Moseby and O'Donnell 2003).

The design of an exclusion fence must be specific to the behaviour of the animals it aims to exclude, as well as taking into consideration the native animals it encloses, and those that may be affected by its presence. There are also a variety of environmental and landscape features to be considered that may reduce the effectiveness or durability of a fence. Exclusion fences tend to be designed based on past experience rather than through a process of experimental trials. Hence, their effectiveness (or lack of) is only discovered after construction. Consequently, there frequently follows a cycle of modification and re-development to overcome unforseen problems. This process has been undertaken independently by organisations and individuals across Australia and throughout the world, and, therefore, there exists a myriad of fence designs for a diverse range of situations.

Coman and McCutchan (1994) conducted a comprehensive review of fox and feral cat exclusion fencing in Australia that has become an invaluable guide for many fence managers. The present document expands on Coman and McCutchan's report by updating information on predator exclusion fencing and by including reviews of fences designed to exclude feral pigs, feral goats and feral rabbits. Predation by dingoes and feral dogs is not a listed threatening process under the EPBC Act (1999). However, because of the long history of dingo exclusion fencing in Australia, these fences will also be discussed.

In particular this report provides a review of the published and unpublished literature and the expert knowledge of fencing managers and pest researchers as relevant to feral animal exclusion fencing. This incorporates a review of the behaviour of the feral species, which will dictate the minimum fence specifications, and the behaviour of non-target species that may damage the fence or be affected by it. Additionally, key factors that should be considered when planning the construction of an exclusion fence are discussed, and knowledge gaps that were identified during the process of this review are highlighted, with experimental trials suggested to address these gaps. A catalogue of existing fence designs is provided at the end of this report with an evaluation of the cost and effectiveness of each design, where known.

1.1 To fence or not to fence?

A significant component of vertebrate pest control revolves around decisions linking the amount of resources (cost) that will be expended and what benefit that expense will deliver. Ideally, the effects that various control strategies, and hence different costs have on delivering these benefits should be understood before proceeding. Unfortunately the future benefits of feral animal control are in biodiversity gains and can not easily be calculated (in a financial sense). A more useful approach is cost-minimisation / benefit-maximisation; this is essentially a comparison of the costs of various strategies that could be employed to achieve a stated outcome. Costs associated with the most effective strategy may mean it is not the most efficient strategy e.g. walking baits into an area will effectively expose all of the targeted pest species to a poisoned bait, however this may not be the most efficient way of achieving this.

The general assumption behind constructing a fence is that it will protect or facilitate a recovery in a specified environmental value by preventing feral pest species reinvading an area once they have been eradicated, thus reducing the long-term costs associated with on-going pest control. If eradication of the pest species within a given area is not the necessary outcome, alternative approaches to building a fence should be explored.

Criteria for eradication

Eradication programs seldom proceed exactly according to the original plan (e.g. Parkes 1984). It is therefore advantageous if those conducting the eradication attempt, both those providing the funds and those doing the work, believe it is possible and are committed to the task (e.g. see Brown and Sherley 2002).

There are four **critical** conditions that must be met before eradication can be achieved (Parkes 1990), and two additional conditions that are desirable and make success more likely if they too are met (Bomford and O'Brien 1995). The critical conditions (the first four) and the desirable conditions (the last two) are:

- ***All individuals (or at least all reproductive individuals in source populations) must be at risk from the lethal control.***

Eradication will fail if a viable population remains in some physical or behavioural refugia (Parkes 2002, Forsyth et al. in press). Physical refuges are obvious; some animals are not exposed to the control tool, e.g., some foxes live in areas where no poisoned baits are laid. Behavioural refuges are a function of the pest, e.g., some foxes will not eat poisoned baits.

- ***The pests must be killed at rates faster than they can replace their losses (by in situ breeding) at all densities.***

Many animal populations increase their productivity and/or decrease their natural mortality rates as their density declines, usually because their per capita food supply increases. Many eradication operations have failed (Parkes 2002), or been long-drawn out affairs with a high risk of abandonment (Parkes 1984) because this criterion was not met.

- ***The risk of immigration must be zero.***

The risk of immigration into the enclosed area (i.e. the risk of the fence being breached) must be so rare that the costs of eradication are favoured over the costs of conducting sustained control (without an exclusion fence) to achieve some target feral animal density at which the impact of the pest is acceptable. The costs associated with killing immigrants will depend on the method, duration and intensity of control required, and as such cannot be easily calculated.

The rate at which a fence is breached is a critical, and often an unknown factor. Monitoring the internal perimeter of the fence, especially around weak points such as roads, waterway crossings and at any seaward ends, as well at likely dispersal pathways, will give the highest probability of detecting feral animal incursions. Fence breaches may occur more frequently during the species' dispersal and breeding seasons, as there may be more pressure on the fence at these times.

- ***Survivors must be detectable at low densities.***

Early detection and elimination of survivors (or immigrants) is a key part of any efficient eradication campaign. When pest animal densities are controlled to very low levels it is difficult to determine if the species has been eliminated or if undetected survivors still persist. Unless intensive monitoring occurs, these may only be detected by chance or when population numbers rise again. There are models that allow estimation of the effort required to detect the presence of rare animals with a specified probability (e.g., Hone 1994; Choquenot et al. 2001; MacKenzie et al. 2002). Sampling strategies taken from this search theory will ensure optimal allocation of monitoring effort (Haley and Stone 1979).

- *Discounted cost-benefit analysis should favour eradication over sustained control.*

If the conservation benefits can be achieved without killing all pests, and if the short-term costs of eradication (combined with the costs of fence construction and on-going maintenance) exceed the long-term costs of sustained control, it may be better to undertake sustained control and invest the additional resources elsewhere.

Experience suggests that the costs to detect and kill the last few percent of a population will be as much as that expended to get to that point. For example, in eradicating possums from Kapiti Island (NZ) 6% of the total direct cost was spent on killing the first 11 500 possums, but 25% was spent on removing the last 80 possums (Cowan 1992).

- *The socio-political environment must be favourable.*

For a variety of reasons not all people may agree with an eradication campaign. These reasons include: consideration of the pest as a resource, ethical objections to killing pests, objections to the methods used, and cultural objections to the plan. It is not vital to reconcile all objectors with the process, but it is wise to reconcile those who might present a risk to its success.

1.2 Threatened native fauna that may benefit from feral exclusion fencing

The native species that are listed under the *EPBC Act* 1999 and considered to be threatened by at least one of the feral species discussed in this review are listed in Appendix 2. These species would benefit from the eradication of the highlighted feral species from critical habitat patches, and exclusion fencing may be used to facilitate this. However, exclusion fencing will not necessarily be the most feasible or effective management option, and therefore, consideration should first be given to those factors discussed in section 1.1. It should also be noted that Appendix 2 does not constitute a comprehensive list of all species likely to benefit from the provision of an area free of feral animals. Numerous species that are not nationally threatened, but have declined either in individual States or Territories, or on a regional scale, due to the threats posed by feral animals, are also likely to benefit. For example, at the Arid Recovery Project site, South Australia, and Heirisson Prong, Western Australia, significant increases in populations of the spinifex hopping-mouse (*Notomys alexis*) the pale field-rat (*Rattus tunneyi*) respectively, were observed following the eradication of feral animals from areas within exclusion fences (Arid Recovery Project 2002, J. Short pers. comm.).

1.3 Limitations of this report

This report provides a comprehensive overview of those factors that should be taken into consideration when planning the construction of a feral animal exclusion fence. It also describes some of the design solutions that have been developed by managers of exclusion fences to overcome commonly encountered problems. However, every fencing situation is unique, and information provided is not intended to act as a substitute for the advice that can be obtained from qualified fencing contractors or consultants (preferably those that have had substantial involvement in the construction of exclusion fencing). No exclusion fence will be effective unless it is meticulously planned and constructed.

2 Fence design review methods

The review of exclusion fence designs in this report followed a two stage process. In the first stage a comprehensive knowledge review was conducted, which entailed a search of the published and unpublished literature, and the collection of information from pest animal researchers. This determined the relevant behavioural capabilities of the feral species of interest, and identified fence designs that have been formally trialed and documented. In the second stage a survey of existing exclusion fences in Australia was conducted to identify additional fence designs and to gather advice and information from people with considerable hands-on, practical fencing experience.

2.1 Knowledge review

An electronic referencing database (Wildlife and Ecology Studies Worldwide 1935 – March 2003, NISC DISCover, National Information Services Corporation, Baltimore, USA) was searched for published literature relating to feral animal exclusion fencing worldwide. Additional, applicable references cited in this literature were also obtained. Key pest researchers and field officers from agencies across Australia (see Appendix 1) were contacted to locate any unpublished data or documentation on the effectiveness of exclusion fence designs. The details of those persons who have provided information, cited as a personal communications, are provided at the conclusion of this report. An internet search was also conducted to locate information in the form of feral animal 'fact sheets' that are typically produced by government agencies.

2.2 Survey of existing fences

Conservation managers, or their equivalent, in each major government conservation or land management agency in Australia were contacted and asked for their assistance in identifying staff within their organisation, or from private organisations within their jurisdiction, that manage feral exclusion fences. People referred by these managers were contacted and, where possible, on-site visits were arranged. Discussions with fence-mangers, directed by a questionnaire (see Appendix 3), determined the purpose of their exclusion fence (in terms of the species or communities it protects and the species it excludes), the design of the fence, the fencing materials used, the costs associated with the fence, the frequency of fence maintenance, the effectiveness of the fence, and any impacts the fence has had on non-target species.

Table 1. Fences surveyed during this review*

Fence name/location	Fence Area (ha)	Managing agency	State
Tidbinbilla Nature Reserve	901	Environment A.C.T.	A.C.T.
Watarrka National Park	120	Parks and Wildlife Service	N. T.
Calga Springs Sanctuary	32	Privately owned	N.S.W.
Living Desert Wildlife Park	180	Broken Hill City Council	N.S.W.
Scotia Sanctuary	8,000	Australian Wildlife Conservancy	N.S.W.
Currawinya National Park	2,800	Queensland Parks and Wildlife Service	QLD.
Cleland Wildlife Park	35	National Parks and Wildlife	S.A.
Venus Bay Conservation Park	2,000	National Parks and Wildlife Service	S.A.
Arid Recovery Project site	6,000	WMC Resources, Friends of the Arid Recovery Project, the Department of Environment and Heritage and the University of Adelaide	S.A.
Yookamurra Sanctuary	1,100	Australian Wildlife Conservancy	S.A.
Royal Botanic Gardens Cranbourne	370	The Royal Botanic Gardens Board	VIC.
Woodlands Historic Park	300	Parks Victoria	VIC.
Hamilton Community Parklands	100	Parks Victoria	VIC.
Little Desert Nature Lodge	234 [1]	Privately owned	VIC.
Ellen Brook Sanctuary	30	Department of Conservation and Land Management	W.A.
Twin Swamps	150	Department of Conservation and Land Management	W.A.
Peron Peninsula	105,000	Department of Conservation and Land Management	W.A.
Paruna Sanctuary	2,000 [2]	Australian Wildlife Conservancy	W.A.
Karakamia Sanctuary	260	Australian Wildlife Conservancy	W.A.
Heirisson Prong	1,200	Useless Loop Community Biosphere Project Group	W.A.

1 This area comprises two or more separate enclosures
2 This fence does not enclose the protected area but is a linear barrier used to restrict the immigration of feral animals into an area where broad-scale control operations are conducted.
* Note that the contribution of Earth Sanctuaries Ltd to the development of exclusion fence designs in Australia is acknowledged. For reasons of being commercial in confidence, exclusion fences on Earth Sanctuaries properties could not be included in this report.

3 Survey results

The managers of 20 exclusion fences from Western Australia, South Australia, Victoria, New South Wales, Queensland, the Northern Territory and the Australian Capital Territory were surveyed (Table 1). For the remainder of this report these fences will be referred to by their name or location as it appears in the first column of Table 1. All of the surveyed fences were (combined) fox, cat and rabbit exclusion fences. The review found that fences designed to solely exclude rabbits vary little in their design and therefore it was decided these required only limited investigation. We were not able to locate any exclusion fences (except for small experimental exclosures) designed to exclude feral pigs and goats from conservation reserves. However, a number of pest researchers and fence managers from the agricultural sector were contacted to obtain fence designs and advice. As dingo exclusion fences have been included as an adjunct to this review, search efforts were restricted to contacting researchers and fence managers by phone to obtain relevant information.

Table 2 provides a summary of those survey results that are likely to be of most interest to the reader. The remaining information was used by the authors to help determine the effectiveness of the various fence designs and as a basis for many of the recommendations in this report.

In line with the notion that no fence is likely to be 100% effective 100% of the time (Aviss and Roberts 1994, Coman and McCutchan 1994), most fence managers interviewed during this review regarded their fence as sufficiently effective despite tolerating occasional feral animal incursions (Table 2). Only 42% of the enclosed areas are systematically monitored to detect such incursions. Those fences that managers regarded as ineffective or only partially effective are either in the process of being upgraded or will be upgraded in the future if additional funding is secured. The inadequacies in these fences were identified as most-probably relating to insufficient voltage in the electric wires, gaps forming between the fence's mesh body and electric wires, and the formation of gaps at gateways.

Only the fence at the Arid Recovery Project has undergone some form of experimental testing to determine its design. Most other fences were designed by consulting with other exclusion fencing managers or pest researchers. A third of all survey participants were unsure how their fence design was conceived, usually because this information had been lost over time often subject to staffing changes.

The review participants were all open in their discussions of the successes and failures of their fences, and these discussions were reinforced by visits examining the fences in question. However, since many of the fenced reserves are not systematically monitored for feral animal incursions, it is not possible to determine whether all assessments of fence effectiveness were accurate and objective – this is not a criticism of fence managers but is a common concern regarding assessments of fence effectiveness. We do not discount the possibility that some managers were unaware of all breaches of their fence.

Table 2. Summary results from the surveys of existing cat, fox and rabbit exclusion fences

Not all questions were answered by every survey participant, therefore the sample size (n) is provided in the column subheadings. Although only 20 fenced sites were surveyed, two of these had two different fence designs, so, where relevant, the sample size is 22. It should be noted that the frequency of fence inspections will be partially dictated by the length of the fence ie. it is not feasible to check a 50 km fence daily.

Conservation values fences were built to protect1 (n=20)	
Reintroduced fauna	75%
Resident native fauna	65%
Display animals	10%
Research conducted to determine the fence design (n=22)	
Consultation within the industry	68%
Experimental trials	5%
Unknown	27%
Fence heights (n=22)	
Range	1.1 – 2.4 m
Average	2.0 m
Fence length (n=20)	
Range	2 – 50 km
Average	11 km
Fences that use electric wires (n=22)	
Yes	91%
No	9%
Voltage of electric fences (n=20)	
Range	2.5 – 12.0 kV
Average	6.1kV
Sites that conduct feral animal control in a buffer area outside the fence (n=20)	
Control	50%
No control	50%2
Frequency of fence checks (n=20)	
Daily	5%
2–4 times weekly	30%
Weekly	45%
Fortnightly	10%
Monthly	10%
Regular maintenance requirements1 (n=19)	
Damage due to falling branches	21%
Fixing holes under fence	26%
Electrical problems	42%
Vandalism	26%
Corrosion/wear & tear	42%
Vegetation & substrate clearance	16%
Average weekly maintenance requirements – including fence checks (n=15)	
0.01 – 0.5 hrs/km	40%
0.51 – 1.0 hrs/km	20%
1.01 – 1.50 hrs/km	27%
1.51 – 3.0 hrs/km	13%
Average	0.9 hrs/km
Monitoring for feral animal incursions (n=19)	
Systematic monitoring	42%
Opportunistic observations	58%
Perceived fence effectiveness (n=20)	
Effective	70%
Ineffective	5%
Partially effective	15%
Unknown	10%
Fences that have recorded breaches (n=20)	
Yes	80%
No	20%
Fences that have caused non-target animal injuries (n=19)	
Injuries recorded	85%3
No injuries	15%

1 Survey participants often nominated several categories and hence percentages do not sum to 100%.
2 67% of the sites not undertaking buffer control are not permitted to do so due to restrictions related to their locality such as objections from neighbouring landholders, residential zoning restrictions and their proximately to public access areas.
3 Injuries to non-target animals at all sites were recorded infrequently.

4 Environmental and landscape considerations

Features of the local environment such as the topography, substrate, vegetation density, climatic conditions and geographic location may place constraints on the fence design, alignment and construction materials. These factors should be taken into account in the planning stage of any fence to ensure that the effectiveness of the fence is not compromised.

4.1 Topography

The topography of an area will influence a number of facets of fence design. For example, fence-post spacings will need to be closer in undulating areas compared to flat areas and this will alter the cost of the fence. It may also be difficult to maintain a consistently small gap beneath fences (without aprons) in areas with uneven and undulating ground.

Different topographies will alter the effective height of fences. A fence constructed on a slope will have a lower effective height from the perspective of an animal attempting to jump it from the upper slope – in such a case the fence height should be increased accordingly. At the Melbourne Wildlife Reserve, Victoria, for example, a fox on a slope uphill from an exclusion fence was able to jump from a standstill to the top of a fence-post 2.1m high (G. Paras pers. comm.). Conversely, a fence will effectively be higher from the perspective of animals that are attempting to jump it from the downward side of the slope, and consequently, it may be economical to decrease the height of the fence. In the Northern Tablelands Region, New South Wales, the Department of Environment and Conservation recommend a 1500 mm high dog fence (See p 17 of the fence design catalogue) but reduce this to 900 mm when the outside of the fence faces a steep downward slope (D. Hardman pers. comm.).

Large boulder tumbles or piles of debris beside a fence also decrease the effective fence height (Fig. 1). Fences should either be aligned so that they do not pass close to such features or the fence height in these areas should be increased so that the measurement from the top of the boulders or debris to the top of the fence is equivalent to the fence height (from the ground to the fence top) elsewhere.

Figure 1. An example of how to successfully negotiate a boulder escarpment.
The fence at Calga Springs Sanctuary is an example of where increasing the fence height has been necessary in negotiating a boulder escarpment. Note how the large mesh apron has been securely bolted to the rock surface.

4.2 Substrate

Substrates that are prone to erosion may cause the fence to be undermined or result in soil build-up against the base of the fence. This is particularly problematic where fences cross dynamic landscape features such as sand dunes or beaches. At the Arid Recovery Project site heavy rubber matting has been placed over the wire netting apron along dunes so that the wind does not excavate the sand from beneath the fence (see Fig. 7a). At Heirisson Prong, where the fence crosses the beach, tidal erosion causes similar problems but this has been remedied by placing rocks on either side of the fence (B. Turner pers. comm.). Similar solutions may be feasible elsewhere.

The build-up of debris, sand, or other soils, against fences decreases their effective height. It also decreases the distance between the ground surface and low electric wires which can put a greater range of non-target species at risk of electrocution, and if the electric wire is buried it will cease to function. Other than manually clearing the substrate build-up, no simple solution to this is known and it may therefore be best to align the fence such that it avoids likely problem areas if possible.

Fence designs that do not include a wire netting apron usually rely on the bottom fence wire or prefabricated mesh to be held at a small and constant distance from the ground surface to prevent animals pushing beneath the fence. This may not be achievable if the substrate is soft and subject to erosion, or prone to digging by target or non-target fauna. In this case an apron may need to be added. However, even the addition of an apron may not completely deter digging animals. At the Royal Botanic Gardens Cranbourne, for example, wombats (*Vombatus ursinus*) and rabbits, which are abundant in the area, regularly dig holes in the sandy soil under the apron of a predator exclusion fence, necessitating regular maintenance. In contrast, managers of fences that are built on hard substrates reported minimal to no digging beneath their fences.

4.3 Waterways and peninsulas

The alignment of a fence should be planned so that it crosses the minimum number of waterways, be they permanent streams or ephemeral floodways, as these are considered to be weak points in any fence. Major drainage channels or permanent waterways should be avoided wherever possible. If this is not an option, the fence should be aligned so that it crosses waterways at locations where the water flow is lowest and erosion of banks is minimised. The following advice regarding the location of waterway crossings is provided by the Water

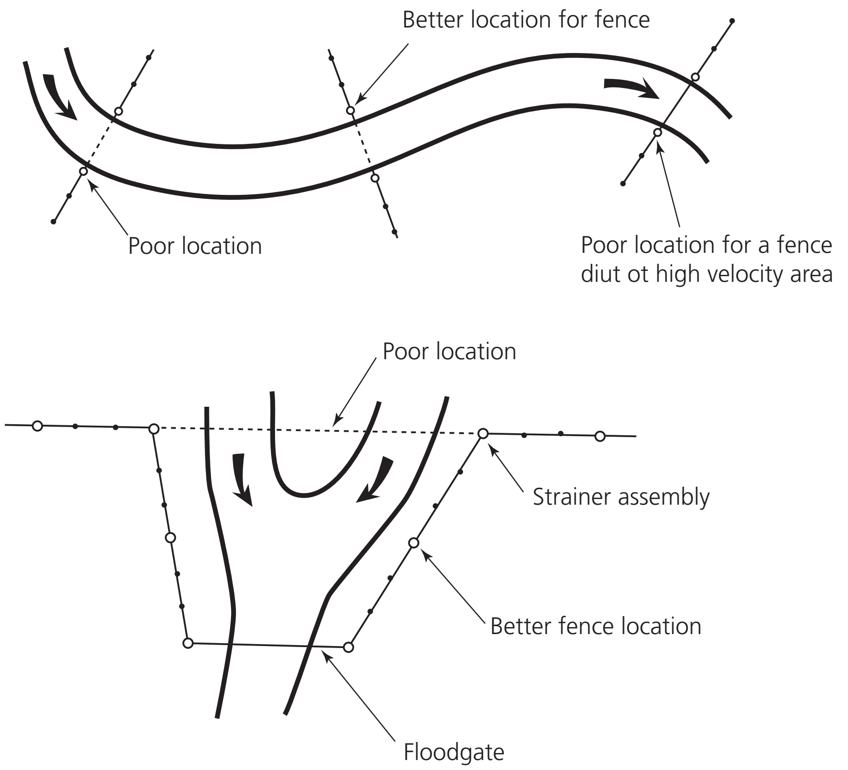

Figure 2. Recommended location of a fence that crosses a waterway.
A fence should always be built along a straight section of the river or at a crossover point in the middle of a meander where the main flow is naturally directed to the centre of the channel. (Reproduced from Water Note 19 'Flood Proofing Fencing for Waterways', courtesy of Department of Environment, Western Australia)

and Rivers Commission, Western Australia (Chalmers 2000): The force exerted by the waterway increases with stream depth and velocity, and it is therefore best to locate any fence crossing as far upstream as possible from the lowest point of the stream channel and at naturally high points in the land's topographical profile. Fence crossings should also be located along straight sections of the waterway because the high water velocity at the outer edge of bends may cause scouring of the bank, undermining the fence (Fig. 2). Additionally, boggy areas should be avoided as the fence will be weaker at these points compared to those areas with hard, stable soils. If a fence is likely to have to withstand occasional flood events, the fence in the flood path should be constructed accordingly. The spacing, depth and type of posts used will determine the fence's strength against floodwaters. A fence will be more resilient to floodwaters if the posts are driven rather than dug into the ground, if they are embedded deep in the ground or firmly secured to it, if the soils are firm rather than dry and sandy, and if the posts are not spaced too closely, as this increases the flow resistance (Waratah® – BHP Steel 1993, cited in Chalmers 2000). To prevent large-scale damage to a fence in the event of a flood, it has been suggested that 'at risk' sections of the fence are isolated from the rest of the fence by placing end strainer assemblies either side of the waterway (Addison 1994).

There are several design features used at waterway crossings to ensure the integrity of the fence is maintained. Whenever possible, water should be channelled beneath a fence so that the structure of the fence is not weakened and corrosion of wire products is minimised. Fences that cross minor ephemeral floodways, such as surface water run-off areas in the arid zone, may require little modification. For example, the fence at Scotia Sanctuary has short sections of sacrificial fencing uphill from the main fence to catch debris which, in conjunction with floodwaters, could cause damage. The fence at the Arid Recovery Project site has an increased mesh apron held down with rocks at minor ephemeral drainage lines. At larger drainage channels, a bed of rocks below the apron (with additional rocks on top) permits water flow beneath the fence without causing erosion (Fig. 3a).

Concrete culverts are most frequently used to channel larger water courses beneath a fence. These should be fitted with a metal grate or cover over the opening to prevent the passage of feral animals (Fig. 3b,c). This appears to be an adequate solution although the grate must be able to be removed to be regularly cleared of

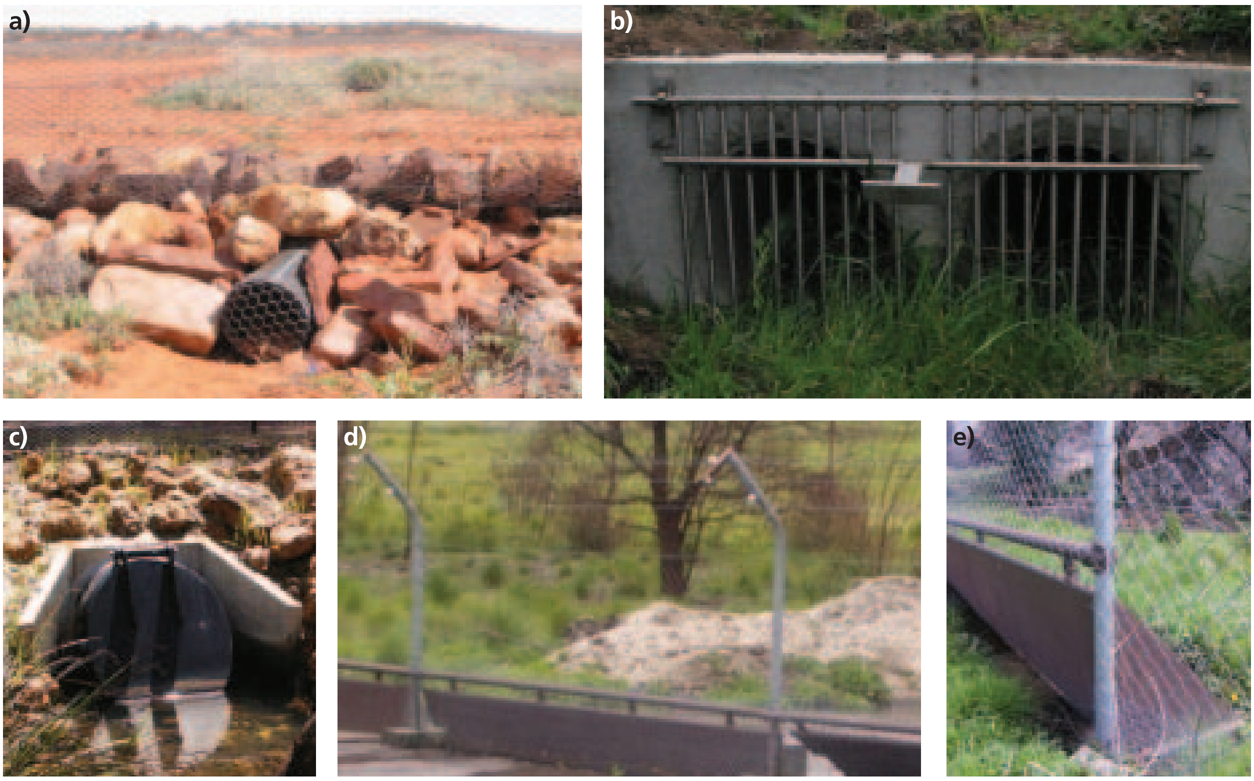

Figure 3. Waterway crossings.
a) Plastic pipes in rock-beds are sufficient for minor ephemeral drainage lines. b) and c) culverts suitable for creeks and drainage lines. Hinged grills b) and covers c) permit variable water flows but exclude feral animals. d) Floodgates, preferably with metal sidings d) can be used to cope with highly variable water flows.

debris. In some situations, these grates are hinged at the top allowing unrestricted flow during flood events or in response to the build-up of debris. Hinged grates must be sufficiently heavy to prevent feral animals opening them. The mesh size in the grill should be as large as practical to minimise the collection of debris and to allow the passage of aquatic fauna, but small enough to exclude feral animals. Solid covers are likely to put a greater restriction on the movement of aquatic fauna.

Floodgates can be used for streams that experience high flow (see Fig. 3d,e) and are most appropriate for waterways that typically remain within their channel during flood events (Chalmers 2000). However, floodgates will restrict the movement of aquatic fauna (except possibly during high flow events) and may therefore be best used as a backup system to cope with flood waters that overflow standard culvert set-ups. To ensure gaps do not form when floodgates open, metal sidings are recommended (Fig 3e; K. Phillips pers. comm.). Metal floodgate grills used in dog fences in South Australia often incorporate floats, such as sealed polypipe tubing, at their base to assist them in opening (M. Balharry pers. comm.).

Peninsulas are often used for the establishment of endangered species recovery programs because the re-invasion of feral animals (following their eradication) can be prevented (or at least minimised) by concentrating control efforts, such as exclusion fencing and baiting programs, across the narrow peninsula neck. However, it is particularly difficult to curtail the passage of animals, particularly foxes, around or through the seaward ends of these fences (Patterson 1977, Short *et al.*1994). In fact all three fences in Australia that cross peninsulas (Venus Bay Conservation Park, Peron Peninsula and Heirisson Prong) have experienced this problem (D. Armstrong, C. Sims and B. Turner pers. comm.). This occurs either because animals are able to pass around the end of the fence during very low tides, or because they pass through holes in the fence created by corrosion or storm damage.

The planned alignment of a fence across a peninsula should take into account the coastal conditions at the seaward ends. If one or both ends of the fence terminates at a cliff edge, that cliff/s must be sufficiently precipitous to prevent the target feral animals from passing around the end. This factor strongly influenced the alignment of the fence at Venus Bay Conservation Park (Fig 4a; D. Armstrong pers. comm.). If the fence is to terminate in the sea and the water is relatively shallow, then it may be necessary to extend the fence a considerable distance into the water to account for full tidal variation (Fig 4b). Some fences also curve back towards the beach to try and encourage animals that may be following their length to return to the shore. A similar concept trialed by the Xcluder® Pest Proof Fence Company, New Zealand, is to create a spiralled section of fence on the shore to direct animals that are moving along the fence away from the tidal zone and back along the fence in the opposite direction. This system, tested on common brushtail possums (*Trichosurus vulpecula*; T. Day and R. MacGibbon unpubl. data), capitalises on the tendency for animals to dogmatically follow fence lines and not necessarily seek alternative routes. This may not prove as successful for seemingly 'intelligent' species such as foxes, but may prove useful as an additional security measure and could possibly be used to funnel animals towards traps or bait stations.

There are a number of factors that increase the need for ongoing fence maintenance in coastal environments. The accumulation of salt crystals on fences causes voltage leakage from electric wires on nights of heavy dew (Cash and Able 1994, Short et al. 1994) and may affect the

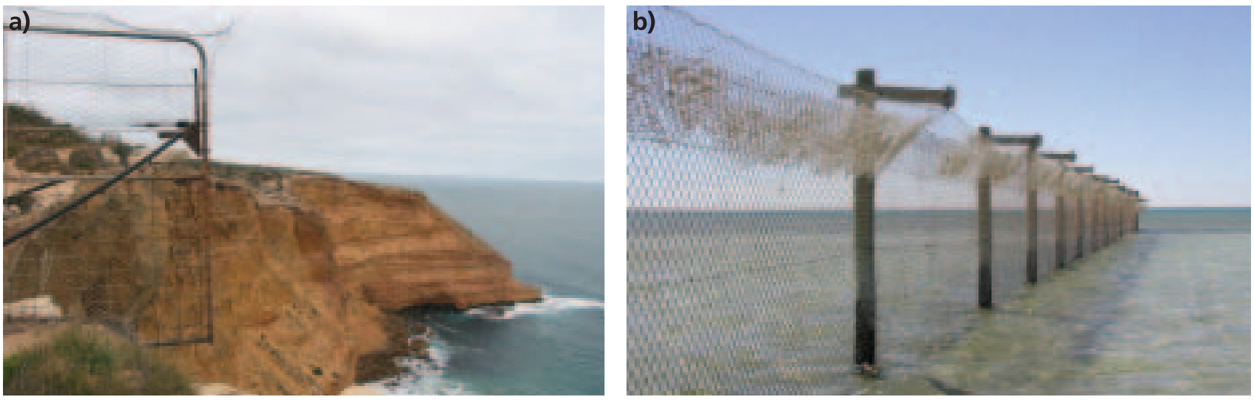

Photo by C. Sims

Figure 4. Seaward ends of peninsula fences.
a) The Venus Bay Conservation Park fence aligned to overhang a sufficiently precipitous cliff. b) The fence across Peron Peninsula extending considerable distance into the sea to take into account the full tidal variation.

function of equipment such as solar panels (Cash and Able 1994). At Heirisson Prong, high-pressure hoses are used to periodically remove salt buildup on electric wires.

Saline conditions cause rapid corrosion of wire products. Plastic coated chain-mesh used in the Peron Peninsula fence, has proven to be a durable solution to this (C. Sims pers. comm.). Mesh made solely of plastic, however, can be chewed through by rabbits and foxes (Short *et al*.1994, McKillop *et al*. 1998, D. Armstrong pers. comm.).

The build-up of debris against fences is frequently problematic, as the weight of this, combined with the increased wave pressure it causes, heightens the likelihood of damage. Additionally, the presence of the fence may slightly alter the coastal geomorphology causing sand and shell build-up along the fence-line. In relatively shallow bays this may decrease the depth of the water to the extent that feral species are more likely to pass around the fence ends (C. Simms pers. comm.).

5 Maintenance

A fence will only continue to be effective if it is regularly monitored and well maintained (McKnight 1969, Sexton 1984, Coman and McCutchan 1994, Hallett 2002). It is important therefore that sufficient labour and funding is apportioned to these tasks. Fence managers interviewed during this study said that their annual maintenance budgets are comprised almost entirely of labour costs (including the cost of monitoring the fence), with little expenditure on materials (discounting the need for major fence upgrades). To provide easy access for fence inspections and maintenance, a vehicle track should be cleared on at least one side of the fence. In a recent audit of dog fences in north-east Victoria, it was noted that poor accessibility was a contributing factor to the disrepair of some fences (Hallett 2002).

The frequency with which a fence should be inspected will be dictated by its maintenance requirements, and these will vary according to the factors discussed below. As a guideline, most operational fences visited during this study were being monitored at least weekly (Table 2). More frequent monitoring in the period immediately after construction may be warranted to detect construction flaws and to check for non-target species that are likely to have a higher rate of collision and entanglement until they become accustomed to the fence's presence. Maintenance issues relating to electrification, feral species and non-target species are discussed in sections 8.3, 9 and 10 respectively. Additional maintenance issues are discussed below.

Quality of materials and workmanship

Poor quality fencing materials and workmanship is likely to increase the maintenance requirements of any fence (Sexton 1984). Sexton (1984) found that most faults in electric fences in the first few weeks after construction were the result of human error. If possible, a contractor who has previous experience in exclusion fencing should be sought to conduct or at least supervise construction. Several fencing managers interviewed during this study told of having to re-build fence sections that were not constructed to a sufficiently high standard to exclude feral animals.

Vegetation control

As mentioned, the clearance of a strip of vegetation on at least one side of the fence is usually required to allow vehicular access. This will also alleviate several maintenance issues (see below) and will serve as a fire-break. The need for further vegetation control will vary according to the type of vegetation the fence passes through.

Ground layer vegetation should be periodically controlled to allow the base of a fence to be easily inspected for holes under or through it. If the fence has a mesh apron some vegetation should be permitted to grow through this to secure it to the ground if it is not held down by other means (ie. pegged to the ground or buried; see section 8.1). Dense, fast growing, ground cover, may preclude the use of fence designs with low electric wires, as vegetation contacting these wires will cause voltage leakage or electrical shorts, and the cost of ongoing vegetation clearance is likely to become a significant maintenance cost. Clearance of ground vegetation may also be difficult beneath electric wire arrangements such as those on sloping droppers (see Fig. 10). Herbicide selection is important (if these are to be used) as some are corrosive to wire products.

In heavily treed areas, branches close to or overhanging the fence should be removed to reduce the risk of damage and the chance that they may facilitate cats and foxes entering the enclosed area. Falling branches and twigs may also accumulate on rigid fence overhangs, shorting electric wires near the top of the fence. This is particularly problematic if a double sided mesh or electric wire overhang that forms a 'V' shape is used, as debris readily collects in the centre of these (G. Fitzpatrick pers. comm.). It is probably more practical to clear all trees that are close to the fence to minimise future maintenance.

Corrosion/wear and tear

Vigilance is needed to ensure that weaknesses in a fence that develop over time are detected and repaired as quickly as possible. Wire netting aprons are usually the first component of a fence to corrode, and this will occur more quickly if the apron is buried in moist soils. Other wire fencing components that touch the ground surface will also be prone to relatively rapid corrosion and therefore the materials used should be relatively easy and cheap to replace. For example, prefabricated netting fences may have a sacrificial plain wire strung between the netting and the ground to allow the gap below the fence to be minimised without the netting having to touch the ground surface.

Storm and wind damage

Fences should be inspected immediately following a storm as strong winds, debris, lightening and flooding can all severely damage a fence. The build-up of wind-blown vegetation, such as tumbleweed, against a fence will increase the fence's wind resistance making it prone to damage (Bird et al. 1997). If this is likely to be an issue, an especially robust fence construction will be required.

Fire

Clearance of vegetation within the immediate vicinity of a fence will act as a fire-break and should go some way towards protecting the fence and the area it encloses from fire. Steel fence posts and porcelain insulators can be used in fire-prone areas to minimise fire damage (Sexton 1984). However, intense fires will destroy electric fence energisers and remove the galvanising on wire products (Sexton 1984), and consequently, even if a fence appears structurally sound following an intense fire it may corrode quickly and require replacement soon after. The fire risk posed by electric fences is discussed in section 8.3.3.

Vandalism

Twenty six percent of participants in this survey noted vandalism or the theft of fence components (mainly solar panels) as a maintenance issue. The motivation behind these acts of vandalism was not clear. At some sites, signs have been erected to educate the public about the purpose and importance of the fence in the hope that this will increase community support for the site and assist in the detection of vandals and fence damage.

Unintentional fence damage may also occur, particularly if vehicles are driven in or near the fenced area at night when fences are difficult to see. The use of reflectors at bends in the fenceline are recommended to alleviate this (K. Moseby pers. comm.).

6 Reducing the challenge to fences

The level of 'pressure' placed on a fence by feral animals is likely to be dictated by the density of feral animals outside the fence, and the relative abundance of resources (particularly food) on opposing sides. Dispersing animals seeking new territories may put greater pressure on the fence than resident animals. A fence that is subjected to little pressure may successfully exclude feral animals, whilst the same fence design may prove less successful in areas of relatively high pressure. Equally, the pressure on a fence may change over time according to the environmental conditions in the area. The fence surrounding the Western Plains Zoo, New South Wales, for example, has been breached by foxes on two occasions – both during times of drought when foxes were presumably food-stressed (P. Cameron pers. comm.).

While the relationship between fence effectiveness and feral animal 'pressure' has not been formally tested, it is frequently cited in the literature (Plant 1980, Blinksell 1985, Environment Australia 1999). Fifty percent of fence managers interviewed during this study conduct buffer control programs utilising poison baiting, shooting, and/or leg hold traps with audio lures. It is important to remember that fencing close to property boundaries may restrict management's ability to conduct feral animal control in the surrounding 'buffer' area.

7 General fence features

Most animals that encounter a fence will first attempt to push under or through it (Lund and De Silva 1994, Day and MacGibbon 2002, Moseby and Read in press). Therefore, the lower sections of the fence in particular must be meticulously constructed and maintained. The pressure on the fence will be greatest at corners (especially inside angles), as animals walk along the fence-line until they reach a corner, and will attempt to cross at this point (Thompson 1979, Day and MacGibbon 2002, Moseby and Read in press). Corners of less than 120 degrees aid animals such as cats, foxes, rabbits and rock wallabies, that are able to brace against, or jump between, adjacent fence panels (Day and MacGibbon 2002, K. Calder pers. comm., T. Bloomfield, K. Phillips and A. Schmitz pers. comm.).

External fence features, such as strainer post stays, will aid animals that attempt to climb or jump the fence and should therefore be avoided (Thompson 1979, Parkes et al.1996, C. Marks pers. comm.). The attention of animals will also be focussed on minor imperfections in the fence, such as protrusions or indentations, that may facilitate them breaching the fence (Day and MacGibbon 2002).

Some animals learn through trial and error to negotiate fences (Patterson 1977, Day and MacGibbon 2002, C. Marks pers. comm.) and there is evidence of individuals learning to breach fences by watching successful breaches by conspecifics (Bird 1994, McKillop and Wilson 1999). Therefore, the true effectiveness of a fence may not become apparent for a period of time after its construction. This has implications for the length of time over which experimental fence trials need to be conducted to ensure that animals that are initially deterred by a fence do not later learn to cross it.

7.1 Aprons

The primary aim of wire netting aprons is to prevent feral animals from pushing or digging beneath a fence. Similar behaviour by non-target animals must also be prevented, as feral animals will readily exploit holes created by native species. While aprons effectively reduce the frequency of hole formation under a fence, they do not always eliminate the problem (e.g. Marks 1998, Fleming *et al*. 2001, C. Wright pers. comm.). Apron sizes of 300 to 600 mm are frequently used, however we are not aware of any research that has been conducted to determine the optimal apron size for Australian species, or to ascertain if increasing the apron size increases its effectiveness in situations where burrowing animals are particularly problematic. Research in New Zealand on brown rats (*Rattus norvegicus*), black rats (*Rattus rattus*), and stoats (*Mustela erminea*), all prolific diggers, showed that most diggings over a shallowly-buried 400 mm apron, occurred within 200 mm of the fence base, with only 11.0% of diggings occurring 200 to 400 mm from the fence, and 1.5% occurring further than 400 mm from the fence (Karori Wildlife Sanctuary Trust Inc. 1998). Other research in New Zealand using house mice (*Mus musculus*), black rats, brown rats, stoats, ferrets (*Mustela furo*), rabbits and common brushtail possums has resulted in similar findings (Day and MacGibbon 2002). Both studies conclude that horizontally buried aprons are more effective than those that are buried vertically as animals that encounter the latter situation sometimes continue to burrow down until they are able to pass under the apron.

Surface-laid aprons are secured to the ground surface, either by pegs, rocks, or simply by letting grass grow through the netting. If the apron is not secured properly, burrowing animals may learn to push under sections of the netting where slight puckering occurs. This puckering has been found to occur more frequently when lower quality netting is used (A. Schmitz pers. comm.). Where soils are hard and difficult to dig in, a well-secured, surface-laid apron seems sufficient. Where soils are soft, and burrowing animals problematic, an apron that is buried just below the surface is likely to be best. This will prevent animals locating the apron edge and exploiting any weaknesses, such as puckering. However buried aprons typically corrode faster than surface-laid aprons because of the moisture retention in the soil.

When creating an apron a separate length of netting can be used and clipped to the vertical netting near the ground. Alternatively a greater width of netting can be used so that the apron is continuous with the vertical netting. The latter approach is considered to be easier and less labour intensive and it decreases the chance of feral animals exploiting gaps that may develop between the clips near the base of the fence where the two pieces of netting are joined (K. Moseby pers. comm.). The disadvantage with this approach is that, when the apron netting corrodes (which will occur considerable faster than the vertical section of netting that is not in contact with the ground – except possibly in very arid areas), a much larger section of netting will need to be replaced and this will be more expensive. When corrosion occurs, completely removing and replacing the netting is preferable to attaching a new apron on top of the old layer, because 'sacrificial rusting' will occur, causing the new netting to corrode considerably quicker than it otherwise would (C. Robertson pers. comm.).

The method used to create an apron should therefore be determined based on the likely frequency with which the apron will have to be replaced (which will vary according to the environment the fence is to be constructed in) and the predicted material versus labour savings that each of the methods would confer.

7.2 Gates

Access gates are often considered to be weak points in exclusion fences. Although gates primarily function to allow human access to an enclosure, they must also function as an effective barrier to feral animal movement. Therefore, the design principles that apply to the fence must also apply to the gate. For example, gaps in, below, or between gates must be smaller than the maximum wire netting size used in the fence if an adequate barrier is to be maintained (Fig 5a–c). Gaps, such as wheel ruts quickly form beneath gates unless a solid concrete or wooden plinth is used. Gaps also frequently form between double opening vehicle gates and therefore a wide, single, vehicle gate is preferred (J. McCutchan pers. comm.). When gates are secured with a chain and padlock the chain should be shortened so that the ends of the chain just meet, and the gate must be tightly fastened. Gaps where the chain is operated through the gate need to be covered when not in use (Fig 5d). A more secure locking mechanism that ensures the gate is correctly aligned when closed is preferable to a simple chain and padlock system (Fig 5c).

The same principles that apply to the spacing of electric wires in the fence body should be applied to gates (see

Figure 5. Gate features.
Effective gates at a) Karakamia and b) the Arid Recovery Project. Note: plinths below the gates are preventing the formation of wheel ruts; the lack of gaps between, or around the gates; the close spacing between the electric wires and the gate (a) and the continuation of the fence design across the gate in (b) to maintain an effective barrier. c) A secure locking mechanism that ensures the gate is correctly closed. d) A simple method of covering padlock holes (a latch on this would add additional protection). e) A common example of electric wires that are spaced too far from the gate to effectively exclude climbing animals.

Section 8.3.1). A problem observed during the survey of existing fences was that electric wires were frequently offset too far from the plane of the gate to adequately contact any animal climbing it (see Fig. 5e). Aside from using electric wires, several unique solutions to deterring climbing animals have been developed using sheet metal (see section 9.1.7).

Gates that function to permit the access of members of the public into a reserve, either by car or by foot, can be problematic in that they rely on these people to adequately close the gate. Pedestrian gates used for this purpose should be designed to close and latch automatically – this is most often achieved by using a spring-hinged gate. The extra security provided by an airlock gate system is ideal as the passage between the two gates ensures that animals cannot slip unnoticed into or out of the enclosed area. Locking mechanisms can be designed for these airlock systems to prevent both gates being opened simultaneously.

Few areas with exclusion fences allow unattended access to public vehicles. Automated vehicle gates that either run on a pressure sensor, or by the guest pushing a button, are utilised at the Little Desert Nature Lodge, Karakamia and Scotia Sanctuary. The use of these ensures correct gate closure.

7.3 Electrification

Electrification is increasingly being used in exclusion fences because it provides a cheaper alternative to traditional wire netting fences (Campbell *et al*. 1990, Bird 1994) and because it may increase the level of protection of a standard barrier fence (Hone and Atkinson 1983, Marks 1998, Fleming *et al*. 2001, Poole and McKillop 2002). Of those fences surveyed during this review, over 90% of fox, cat and rabbit fences (combined) incorporate electric wires (see Table 2), as do 70% of feral goat, pig, rabbit and dingo exclusion fence designs (see fence design catalogue).

McCutchan (1980) remarks that "Electric fences should succeed with any types of animals which are sufficiently intelligent to learn and remember that touching the fence may result in a shock, but not so intelligent as to be able to find out how to avoid a shock". Conditioned avoidance of electric fences has been demonstrated for a variety of species, including pigs (Hone and Atkinson 1983), foxes (Patterson 1977, Poole and McKillop 2002), goats (Niven and Jordan 1980), rabbits (McKillop et al. 1992, McKillop and Wilson 1999), dingoes (G. Gray unpubl. data cited in Campbell et al. 1990), wombats (Marks 1998) and brush-tailed possums (Clapperton and Mathews 1996), although the latter species sometimes endures numerous shocks before developing avoidance behaviour (Clapperton and Mathews 1996). Not all individuals of these species will behave similarly towards electric fences, and there are reports of individual pigs, foxes, dingoes, goats and rabbits learning to avoid shocks from electric fences either by jumping over them (McKillop and Wilson 1999), pushing or digging under them (McKillop *et al*. 1992, Bird 1994, R. Henzell pers. comm.), or running through them at speed (Allen 1984). Feral cats have been observed sustaining numerous electric shocks, sometimes resulting in a frenzied and often successful attempt at crossing a fence (Day and McGibbon 2002, Moseby and Read in prep.) although reactions vary considerably between individuals (Moseby and Read in prep.). Foxes under trial conditions have been found to quickly learn how to overcome various arrangements of electric wires (C. Marks pers. comm.).

The speed with which an animal can negotiate electric wires, and the level of contact it is forced to make with them is likely to have a significant bearing on the effectiveness of a fence. Most animals that receive a shock will naturally retreat from a fence (McKillop and Sibly 1988), however there are several scenarios where the effectiveness of electric fences may decline:

1) if an animal is able to pass quickly between the electric wires it may avoid the electric pulses, which must not be more frequent than one per second (see Australian/New Zealand Standard 3350.2.76),
2) if most of the animal's body has passed between the wires before it receives a shock, its momentum may carry it through the fence regardless, and finally,
3) if the electric wires are relatively widely spaced then, even if the animal must proceed slowly through them, it may not receive a shock due to the insulating properties of its fur.

Therefore, to maximise the effectiveness of electric wires in exclusion fences the wires should form, or be used in conjunction with, a sufficiently challenging physical barrier (McKillop and Sibly 1988). This will reduce the speed of an animal's approach to the fence and increase the difficulty of crossing the fence.

The size of shock an animal receives will determine its subsequent response, with severe shocks more likely to result in future avoidance (McKillop and Sibly 1988). McKillop and Sibly (1988) note that wild animals typically investigate unfamiliar objects with their nose and, being a poorly insulated and highly innervated area, the animal receives a severe shock as a consequence. They suggest that making a wire more conspicuous by attaching objects such as plastic strips to it may further encourage this form of investigation and prevent animals unwittingly running into, and through the fence. Cats have been found to used their noses to investigate low electric wires (ie. 300 mm above the ground) but to use their feet to investigate electric wires they encounter when climbing fences (K. Moseby pers. comm.). Increasing the conspicuousness of these higher wires may therefore have little impact.

If they are to remain effective electric fences need to be monitored regularly to ensure they are functioning to their full capacity. Nearly 40% of survey participants noted repairing electrical faults as a regular maintenance requirement. While learned avoidance of electric fences means that individuals from some species are likely to continue to avoid a fence during short-term power failures (McKillop et al. 1992, McKillop et al. 1993) other species have been found to exploit unpowered fences relatively quickly (e.g. dingoes; Bird 1994, brushtail possums; Clapperton and Mathews 1996). During power failures, electric exclusion fences are also likely to be breached if encountered by dispersing animals that are naïve to electric fencing, and these individuals may teach observing conspecifics to do the same (McKillop et al. 1993, Bird 1994, McKillop and Wilson 1999). Additionally, these animals may continue to breach the fence once it is again powered (Bird 1994).

To impart a shock of sufficient strength, Coman and McCutchan (1994) conclude that a fence's voltage should be maintained as high as possible with a minimum of 5 kV under dry conditions and 2 kV in wet conditions. Fences in this review had an average voltage of 6.5 kV (range 2.5 – 12kV; see Table 2). Voltage should be checked at least daily so that electrical shorts or other malfunctions are detected and promptly fixed. Alternatively, automated monitoring systems, can be purchased to provide an immediate alert of a voltage drop. Wherever possible, mains powered energizers should be used in preference to battery powered energizers (Bell 2002).

7.3.1 Spacing and height of electric wires

The insulative nature of animal fur (Bird 1994, Coman and McCutchan 1994) and the poor earthing properties of dry Australian soil (Plant 1980, Campbell et al.1990, Fleming et al. 2001) mean that animals contacting an electric wire do not always receive a shock. For these reasons an earth wire/ground return system with alternating electric and earth wires that are closely spaced relative to an animal's body size are usually required. This ensures that individuals passing through a fence firmly contact an electric wire and are adequately earthed. Plant (1980) suggests this principal should also be used to prevent animals pushing beneath strained wire fences – an animal pushing beneath the lowest electric wire will receive a shock if it is forced to push over an earth wire placed very close to the ground surface. Surface-laid wire netting aprons are advantageous in this respect – they not only prevent animals pushing beneath a fence but also effectively earth any animal standing on them.

The spacing needed between electric wires to achieve sufficient contact with an animal is deceptively small and seems to be overestimated in some fence designs. For example, wire spacings of no more than 100 mm in the mid-section of fences are required to deter most dingoes (Bird 1994). Coman and McCutchan (1994) recommend wire spacings for foxes and cats of 70 – 90 mm, but also found during trials with dead foxes that a spacing of just 75 mm did not guarantee an animal with dry fur would receive a shock when passing between the wires. Moseby and Read (in prep.) found that cats were able to squeeze between the fence and offset electric wires that were spaced further than 80 mm from the body of the fence without receiving a shock.

The maintenance of precise wire spacings, which is essential to the fence's effectiveness, can be achieved by using the correct wire tension, and relatively closely-spaced droppers and line posts. The spacing between electric wires offset from wire netting fences can be especially difficult to maintain, as slight bulges form in the netting (often exacerbated by kangaroo impacts). Coman and McCutchan (1994) suggest that to minimise this problem, electric wires should be positioned adjacent to the strained support wires that the netting is clipped to, and that additional insulated spacers (such as lengths of polypipe) be added where necessary (Fig. 6).

Electric wires that are offset from the base of the fence are designed to train animals to avoid the fence, lessening the risk of breaches or damage. These should be positioned at the height of the target animal's snout to encourage investigation. Trip-wires, or electric wires on sloping droppers may also slow the approach of an animal to the fence, lessening the chance of the animal charging into, or through it (see pages 4, 8 and 9 of the fence design catalogue). At Currawinya National Park four electric and two earth wires on sloping droppers effectively reduce damage caused by kangaroos and emus to a predator exclusion fence. One or two offset wires may be sufficient in other cases.

Offset electric wires mid-way up netting fences are often used to deter climbing foxes and cats. The effectiveness of electric wires used in this way is unknown but they are unlikely to be as effective as electric wires used near the top of fences in conjunction with a physical barrier. If offset wires are to be used in this way they should be positioned at a height above the level the targeted feral species would normally jump to. Although both cats and foxes are capable of jumping to heights of approximately 1.8 m (Day and MacGibbon 2002, C. Marks unpubl. data), they are most likely to jump onto the fence at lower heights. For example, fence trials conducted at the Arid Recovery Project site showed that cats most often jumped onto the fence at heights of 1.2 –1.5 m (Moseby and Read in prep.).

7.3.2 Australian electrical fencing standards

To ensure that electric fences are constructed and operated safely, compliance with the Australian/New Zealand Standard 'Electrical Installations – Electric Fences' (AS/NZS 3014:2003) is required. The standard provides guidelines for issues such as the provision of adequate warning signs, restrictions on the use of barbed wire, the correct use of energisers, the positioning of electric wires in fences in urban and residential areas, and the height of fences that pass below overhead power lines. The published standard can be purchased from Standards Australia in NSW.

7.3.3 Fire risk posed by electrical fences

Electric fences have been suspected of causing several fires (McCutchan 1980, Sexton 1984), however McCutchan (1980) concluded that the combination of conditions necessary to ignite surrounding vegetation make electric fences a possible but improbable cause of bushfires. He found that an arc can pass through the air between an electric wire and another electrical conductor if these components are separated by several millimetres or less. Alternatively, an electrical 'flashover' can occur across a suitable green leaf that contacts an electric wire and a conductor separated by 20 mm or less. These events will only be capable of starting a fire if very dry, finely divided tinder, such as thistle down, is present between the conductors, and there is also sufficient dry vegetation within the immediate vicinity to be ignited. High temperatures, low humidity and the presence of wind are conditions that will cause the tinder to become suitably dry (McCutchan 1980).

To reduce any potential fire risk in areas where bushfires are a hazard it has been recommended that fences be well maintained, porcelain insulators be used (Sexton 1984), vegetation be cleared in the immediate vicinity of the fence line (Australia Standards and Standards New Zealand 2003) and, in high fire risk seasons, the output voltage be reduced or current-limiting resistors installed (Australia Standards and Standards New Zealand 2003, Sexton 1984). However, Coman and McCutchan (1994) point out that reducing the voltage is unlikely to greatly reduce the fire risk and, because higher voltages are likely to be necessary in the drier months to counteract the poor conductivity of animal fur, this may reduce the effectiveness of the fence.

7.4 Materials and other design concepts

7.4.1 Pine vs steel posts

Treated pine posts are considerably cheaper than their galvanised steel equivalent. However, they present several problems for some exclusion fences. Firstly, they provide a convenient platform for animals, particularly cats, foxes and goats, to jump to. This is only a concern for those fences that are lower than the maximum jumping height of the feral animals in question. Wooden posts also provide an excellent climbing surface

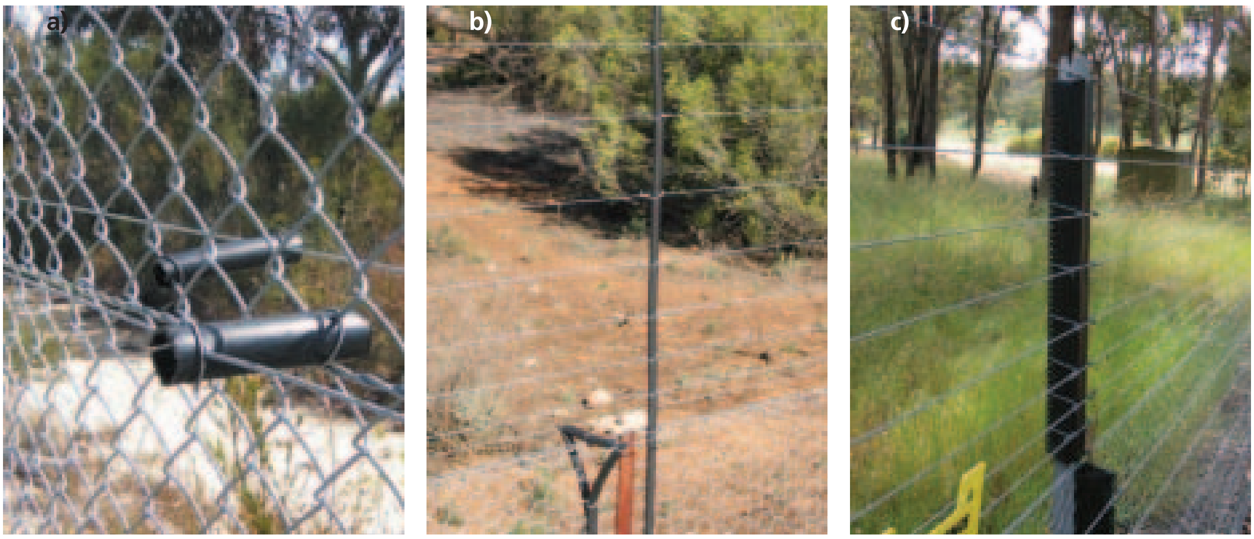

Figure 6. Electric wire spacers.
Custom-made polypipe wire spacers used at a) Calga Springs Sanctuary, b) Yookamurra Sanctuary and c) a commercially available insulated sleeve for steel posts used at Karakamia.

for cats and this significantly increases their chance of breaching a fence (Moseby and Read in prep.). However wooden fence posts are suitable to use if other features of the fence, such as a steel cap (see section 9.1.8, and p 14 of the fence design catalogue), make it physically impossible to breach.

Other criticisms expressed by field staff during this review were that changing environmental conditions sometimes cause staples in pine posts to become loose and wires to need re-straining, and, in some environments, pine posts are less durable than galvanised steel posts (but galvanised steel posts will be less durable in highly corrosive environments; R Ambrose pers. comm.). For the above reasons, some fence managers preferentially use galvanised steel posts and end assemblies.

7.4.2 Wire netting

In most cases, galvanised wire netting or prefabricated netting (depending on the fence design) forms a sufficient barrier to prevent feral animals passing through a fence. Fences that must also serve as a security barrier to people are generally constructed with heavier gauge netting such as chain mesh. Chain mesh is sometimes used in areas where large animals such as kangaroos, pigs, and wombats, that frequently damage lighter mesh fences, occur in relative abundance. The exclusion fence at Peron Peninsula uses plastic coated chain mesh to provide an extremely durable netting to withstand the corrosive coastal environment (C. Sims pers. comm.). Chain mesh is also beneficial in areas with undulating topography as standard line posts, rather than strainer posts, usually provide adequate support at locations where the fence changes direction (A. Schmitz pers. comm).

8 Assessments of fence design and animal behaviour

In Australia, most experimental testing of fence designs has been undertaken in the agricultural sector, driven by the need to reduce stock losses through predation by dingoes/wild dogs (Bird *et al.*1997, B. Harden and D. Hardman pers. comm.), feral pigs (Hone and Atkinson 1983) and foxes (I. Littleton, pers. comm.). The only fence designed for conservation purposes that is known to have been experimentally tested is the Arid Recovery Project fence. The results of this testing will be discussed in section 9.1.4 and included in the feral cat and rabbit behaviour sections. Various fox exclusion fence designs were informally trialed at the Keith Turnbull Institute, Department of Primary Industries, Victoria, resulting in a number of unpublished recommendations (C. Marks pers. comm.).

In New Zealand, several organisations have conducted experimental trials to develop fences that are capable of excluding up to 16 feral species (Karori Wildlife Sanctuary Trust Inc. 1998, Day and MacGibbon 2002). Results of these trials are incorporated into sections 8.1, 9.1.2 and 9.1.8. Testing of this nature has allowed the physical abilities of the target feral species to be quantified (i.e. maximum jump height, climbing ability etc.), providing a sound platform for the development of subsequent fence designs. The recorded behaviour of feral cats is of particular interest to the present review.

Given the limited experimental testing of exclusion fences in Australia, it is not possible to provide assessments of the relative effectiveness of each of the designs shown in the catalogue. A design that is effective at excluding feral animals in a given location will not necessarily be equally as effective in a different location under different levels of feral animal pressure (see section 7) and in the presence of a different suite of non-target species and environmental conditions. Experimental trial conditions, however, tend to represent the worst-case scenario i.e. animals are provided with extreme motivation to breach a fence, or are presented to the fence in unnaturally high densities, and therefore the effectiveness of these fences is more likely to apply to a range of situations.

8.1 Fox and cat fencing

8.1.1 Fox behaviour

Designing a barrier to exclude foxes is particularly challenging owing to their climbing agility, jumping and digging capability and capacity to learn how to overcome obstacles. Foxes are capable of jumping to a height of 1.8 m (C. Marks pers. comm.) and have been observed leaping over farm fences exceeding 1.3 m high (Coman and McCutchan 1994). They also readily scale chain mesh fences over 2 m high (Coman and McCutchan 1994), utilising any solid support to brace their climb (C. Marks pers. comm.), and have been observed hanging upside-down from the ceilings of wire mesh enclosures (C. Marks and T. Bloomfield pers. comm.). Although capable of digging, this does not appear to be their preferred method of breaching fences (Poole and McKillop 2002). Instead, fence managers spoken to during this study reported that foxes more frequently capitalise on holes that have been at least partially dug by animals such as rabbits and wombats.

Foxes have an average skull width of 82 mm (Loyd 1980, cited in Coman and McCutchan 1994) and, given that their shoulder width is not much greater than this, it has been surmised that if a fox can get its head through a hole it can probably get the rest of its body through (Coman and McCutchan 1994). At a site in the United Kingdom a young fox was observed squeezing through a 70 mm gap between a gate and its post (P. Shepherd pers. comm.). The strong jaw muscles possessed by foxes allows them to chew through mesh made of plastic or polythene twine to create holes large enough to pass through (Poole and McKillop 2002, D. Armstrong pers. comm.).

Foxes have proven to be wary of electric fencing, with relatively low fences deterring the majority of foxes in some situations. In Scotland, Patterson (1977) trialed a 450 mm high 3-stranded electric fence across a peninsula to prevent foxes disturbing nesting sandwich terns and eider ducks. No foxes were observed crossing this fence in the first season, although 7% and 25% of encounters resulted in breaches in the second and third seasons respectively and an increasing number of foxes passed around the seaward ends of the fence. In a captive trial, Poole and McKillop (2002) found that foxes did not cross electric strained wire fences and electrified mesh fences (1050 mm high), except when staff entered the fox's enclosures. These studies highlight that, although foxes refrain from crossing electrified fences under most circumstances, they will breach fences given sufficient motivation and their capacity to learn how to negotiate obstacles. This is supported by work in Australia that found foxes quickly learnt to cross fences constructed with various arrangements of offset electric wires (C. Marks unpubl. data).

The ability of foxes to breach fences is enhanced by their persistence at doing so. Researchers have noted that, even after receiving electric shocks, foxes will continually investigate fences (Poole and McKillop 2002, T. Bloomfield pers. comm.). Consequently, as soon as a weakness in a fence occurs, whether it be due to a construction flaw, irregular fence maintenance, or a floodway wash-out, foxes will be ready to exploit it.

8.1.2 Cat behaviour

Several studies in recent years have specifically assessed the abilities of cats at breaching fences (Karori Wildlife Sanctuary Trust Inc. 1998, Day and MacGibbon 2002, Moseby and Read in prep.). A feral cat will first assess the base of a fence (K. Moseby pers. comm.). A 50 mm mesh size is required to exclude both adult and juvenile cats (Day and MacGibbon 2002), although a smaller mesh is likely to be required to exclude small kittens (T. Day pers. comm.). Hitchmough (1994; cited in Karori Wildlife Sanctuary Trust Inc. 1998) found feral cats were able to jump clearly over a barrier of 1.5 m, and Day and MacGibbon (2002) found they could jump to heights exceeding 1.8 m. Cats are also capable of jumping further up vertical netting from their original landing spot (Day and MacGibbon 2002). This behaviour can be particularly problematic if fence corners have internal angles of less than 120 degrees, as cats are able to leap up and across to adjacent fence panels, increasing their chance of getting over the fence (K. Calder pers. comm., Day and MacGibbon 2002). Cats are wary of climbing unstable surfaces such as untensioned, floppy netting (Day and MacGibbon 2002), but solid structures that they can gain purchase on, like wooden fence posts, are readily climbed (Moseby and Read in prep., G. Paras pers. comm.).

The use of electric wires to dissuade cats from climbing fences has had variable success. Trials conducted in captivity have shown that individual feral cats react differently to receiving electric shocks, with some retreating from the electric wire and avoiding contact with it in the future (Moseby and Read in prep.) and others becoming almost fenzied, resulting in a more vigorous, and often successful, attempt at crossing the fence (Day and MacGibbon 2002, Moseby and Read in prep.). Cats in the latter group sometimes withstand multiple electric shocks in the process (T. Day pers. comm.). Feral cats that opportunistically encounter an electric fence are unlikely to be as motivated to cross a fence as feral cats in captive trials. Therefore, it is difficult to know how the results of these captive trials translate when assessing the effectiveness of electric wires in exclusion fences under field conditions.

Photo by B. Parsons, CSIRO Sustainable Ecosystems

Figure 7. Variations in the floppy-top design.
Floppy-top fences at the Arid Recovery Project site (a) and at Heirisson Prong (b). Note the heavy rubber matting along the apron of the Arid Recovery Project fence to prevent wind excavating the sand below the fence.

8.1.3 Floppy panelled fences

The concept of using loosely strung netting to deter climbing animals is not new; Earth Sanctuaries Ltd. are thought to have first advocated the idea, using loosely-tensioned netting in the body of their Warrawong fence (near Adelaide) to deny cats and foxes stable climbing footholds (Coman and McCutchan 1994). Whilst this feature is still being incorporated into many newly-constructed fences, it was obvious during this review that there are varying interpretations of what constitutes 'floppy' netting and we suggest that in some cases the netting is not floppy enough to be contributing greatly to the effectiveness of the fence. Also, Coman and McCutchan (1994) point out that maintaining correct spacings between offset electric wires is extremely difficult with floppy-bodied fences.

8.1.4 Floppy-top fences

The floppy-top fence (Fig. 7a) is an extension of the concept described above and represents the only fence designed to exclude cats, foxes and rabbits that has been experimentally tested in Australia (Moseby and Read in prep.). Variations of the floppy-top design were trialed against 33 feral cats using an experimental enclosure at the Arid Recovery Project site. The final design effectively contained each of 10 feral cats trialed (Moseby and Read in prep.; see p10 of the fence design catalogue for specifications). Foxes were not trialed against this fence because cats, being more adept at climbing and jumping, were considered the more difficult of the two species to exclude (K. Moseby pers. comm.). The trials highlighted several critical design elements required for this fence to function optimally. The floppy top must be 600 mm in length, enabling it to form a full semi-circled cap, and electric wires were found to be necessary to contain all cats. These electric wires were placed at heights of 1200 and 1500 mm (offset from the fence by 80 mm), commensurate with the heights most cats first jumped to, which is also where cats position themselves when attempting to negotiate the floppy top.

There is evidence that, under field conditions, where the feral animal pressure is less than that in the experimental enclosure, slight deviations from these design specifications may not significantly compromise the fence's effectiveness. For example, at the Arid Recovery Project Site, monitoring of regular track transects has shown that the floppy-top fence without electric wires has successfully excluded foxes and cats from a 6000 ha area since December 2001. Another fence based on the Arid Recovery Project design was built at Heirisson Prong in 2001 and utilises two electric wires but has a 500 – 600 mm floppy top that extends at a 45 degree angle (Fig. 7b). Regular spotlighting and track transects at this site have not detected any feral animal breaches, with the exception of when a cyclone destroyed the fence's seaward end.

8.1.5 Rigid overhangs

On their own (i.e. without the use of electric wires), rigid overhangs that extend as a horizontal or angled projection from the top of a fence, provide a challenging but not impassable barrier for feral cats and foxes. For example, a fox at Healesville Sanctuary, Victoria, was observed scaling a 1.8 m fence and climbing upside down along the under-section of a 300 mm horizontal overhang (P. Slinger pers. comm.). Most overhangs are used in conjunction with electric wires and these appear to be considerably more effective.

8.1.6 Electric wires in overhangs and upper fence sections

There is considerable variation in the number and arrangement of electric wires utilised at the top of fox and cat exclusion fences. In some cases overhangs are comprised solely of electric wires and in other cases a mesh overhang is used in conjunction with one or more offset electric wires (Fig 8a–c, also see p 11 of the fence design catalogue). Mesh/electric wire composite designs do not have an overhang but use electric wires as a vertical extension of a wire netting fence (Fig 8d). At this stage there is insufficient information to determine which of these arrangements is most effective. Fence managers report that most fences of these designs are relatively effective in the field. Several fences that have an overhang comprised solely of electric wires have experienced problems. It is thought that the breaches of these fences probably relate largely to the formation of large gaps (greater than 100mm) between the netting and electric wires (see Fig. 9) and as a result of low voltages. However, problems not related to the specific fence design, such as gaps dug beneath the fence, and the formation of gaps surrounding gateways, are also likely to account for some breaches.

Electric wires must be closely spaced to form both a physical barrier and electrical deterrent if they are to function effectively (see section 8.3.1). This is well demonstrated by mesh/electric wire composite fences which have wire spacings of just 50mm immediately above the netting, increasing to 120 mm at the top of the fence, where less of a barrier is required (Fig 8d).

Electric wires used in conjunction with an angled mesh overhang are probably best positioned close to the edge of the overhang so that the animal grabs hold of them when attempting to get over the fence. One or two electric wires would seem to be sufficient.

Figure 8. Electric wires in fence overhangs, or upper sections.
a) A very simple design used at Calga Springs Sanctuary, b) a complex overhang of alternating electric and earth wires at Tidbinbilla Nature Reserve, c) a typical mesh overhang with a single electric wire at the Little Desert Nature Lodge (note the two lower electric wires used to discourage climbing animals and kangaroos) and d) multiple alternating electric and earth wires used above a wire netting base at the Living Desert Nature Park (mesh/electric wire composite design).

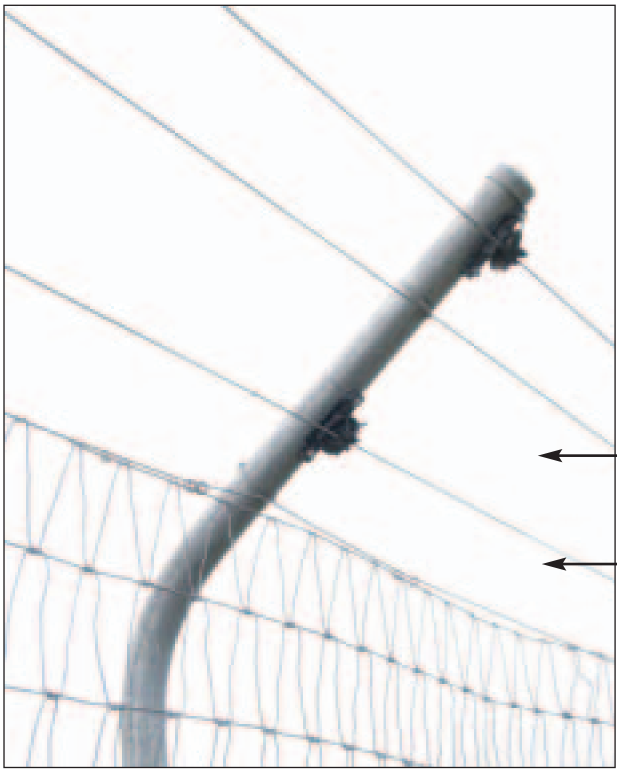

Figure 9. Common problems with electric wire overhangs.

Large gap between wires (greater than 100mm)

Any sags in the netting will cause enlarged gaps to form between the netting and the first electric wire.

8.1.7 Metal bands

Wide bands of steel sheeting are frequently used around tree trunks and power poles to deter climbing animals. Similar bands have been proposed as a means of preventing foxes and cats climbing exclusion fences, removing the reliance on electric wires (Coman and McCutchan 1994, C. Marks pers. comm.). We are aware of two fences that incorporate this feature, one within the grounds of the Karori Sanctuary in New Zealand, and one at the Wildfowl and Wetlands Trust's Arundel Centre in England (both designs also have electric wires on outriggers at the top). Information is only available for the Karori Sanctuary fence, and there is no evidence that this fence was breached by cats, dogs or possums, over a two year period (Karori Wildlife Sanctuary Trust Inc. 1998). The general concern regarding steel bands fitted high on fences is the extreme wind resistance they cause, which renders the design relatively impractical for many environments. Additionally, research has shown that, in captive trials, cats with sufficient momentum are able to scramble past 600 mm wide, metal bands (T. Day and R. MacGibbon unpubl. data). Utilising the steel sheeting as a horizontal or angled projection, as suggested by Coman and McCutchan (1994), would reduce the wind resistance of the steel sheet and probably increase its effectiveness. This concept has been used to deter animals climbing over gates at Heirisson Prong and Currawinya National Park, while gates at Calga Springs Sanctuary and Watarrka National Park are entirely clad in vertically-ribbed steel sheeting. The steel capped design in New Zealand shows the further development of this concept to successfully exclude all climbing animals (See section 9.1.8 below; Karori Wildlife Sanctuary Trust Inc. 1998, Day and MacGibbon 2002).

8.1.8 Capped designs

Steel-capped designs (see p 10 of the fence design catalogue) are being used in New Zealand to create reserves that are free of all mammalian pest species. These designs were developed during extensive experimental trials, with the resulting designs successfully containing all of the targeted pest species (from cats through to house mice) within experimental enclosures (Karori Wildlife Sanctuary Trust Inc. 1998, Day and MacGibbon 2002). The exclusion of cats by these fences is most pertinent to this review and, although foxes have not been tested against these fences, there is no reason to believe they would not also be effectively excluded.

The expense of these fences greatly exceeds the cost of any exclusion fence that currently exists in Australia. A major component of this cost is the mouse-proof mesh which could easily be substituted for wire netting with a larger mesh diameter (30 – 50 mm) according to the suite of animals to be excluded.

8.1.9 Sloping electric fox fences

Fences such as those shown Figure 10 (also see p 89 of the fence design catalogue) represent a markedly different design to that which is typically regarded as an adequate fox exclusion fence. The potential weakness of these fences is that foxes that are sufficiently motivated should theoretically be able to jump them (see section 9.1.1), and for this reason, we believe they are unlikely to achieve complete exclusion, but feel they warrant further research. Of the two designs, the one with the dropper sloping out from the base of the fence (Fig 10b) would seem to present a more physically challenging barrier. Pine posts are best avoided in these fences as they provide a convenient platform for foxes to jump to.

Sloping fox fence 1 (p 8 of the fence design catalogue) and variations of it (with several electric wires on outriggers, rather than on a sloping droppers) have been found to effectively protect free-range poultry from foxes (I. Littleton pers. comm.). In some cases, guard dogs are used in the poultry paddocks as additional fox deterrents (I. Littleton pers. comm.) and it is unknown how much this contributes to the overall fence effectiveness. Additionally, resident foxes outside the perimeter of the fence are not controlled in the belief that they learn to respect the fence and that their presence may deter naïve individuals from entering the area, encountering the fence and potentially breaching it. This idea provides an interesting contrast to the concept of buffer zone control (see section 7).

The fence shown in Figure 10b surrounds the 8,000 ha Scotia Sanctuary. Daily monitoring of track transects has shown no evidence of fox incursions since July 2002 (although cats have been detected and are known to jump through the upper two wires; A. Schmitz pers. comm.). It may be that the electric wires in these fences provide a significant deterrent for most foxes (especially since the wire netting barrier prevents animals from rapidly pushing through fence), and the sloping arrangement may be sufficiently confusing to slow their approach to the fence and make them hesitant to jump it.

These fences have the benefit of being considerably cheaper than taller netting fences (see p 10–14 of the fence design catalogue) but are probably best suited for areas that can tolerate a low rate of fox incursion. Low fences such as these are also seen as advantageous in that they should permit the dispersal of kangaroos which are capable of jumping considerably higher fences. A slight variation on these designs is currently being trialed in southern New South Wales to protect bush stone-curlew (Burhinus grallarius) nests (L. Wheaton pers. comm. Fig. 10a). In this instance the wire netting is being substituted for prefabricated fencing in an attempt to make the fence more permeable to native wildlife.

8.2 Rabbit behaviour and fencing

Rabbit 'proof' fences have been utilised in Australia since the 1880's (McKnight 1969) and have varied little in their design since this time (Fig. 11). Such fences are made of wire netting, typically with a mesh size of 40 mm or less. The Arid Recovery Project tested the mesh size required to exclude independent juvenile rabbits, and found a maximum 30 mm mesh size necessary (Moseby and Read in prep.). This is comparable with British standards that require a 31 mm hexagonal mesh to exclude juvenile rabbits (British Standards Institution

Figure 10. Sloping fox fences.
Fox fences at a) Walla Walla, N.S.W being trialed to protect bush-stone curlew and b) at Scotia Sanctuary, N. S.W.

1948, cited in McKillop *et al*.1988, R. Trout pers. comm.). Trials in the United Kingdom have also found a 50 x 20 mm rectangular mesh to be effective (McKillop *et al*.1998). Plastic meshing has been used but rabbits are able to chew through this (Short *et al*.1994) and, to a lesser extent, through temporary electric fencing made of polythene twine with inter-woven wires (McKillop *et al*.1998).

A mesh height of 900 mm is typically recommended for rabbit exclusion fences (Ministry of Agriculture, Fisheries and Food 1950 cited in McKillop et al. 1988, Hay 1999, Lowe 2002). Rabbits are capable of jumping over fences that are 500 mm high (McKillop and Wilson 1999) and have been observed crossing a 1050 mm high fence (T. Bloomfield pers. comm.). Fence trials conducted in captivity found that two of 14 rabbits crossed a 900 mm high fence but, in the same trials, no rabbits crossed a 750 mm high fence over a four week period (McKillop et al.1988). This suggests that breaches of a 900 mm fence are possible but unlikely to occur regularly. In other trials, a 900 mm rabbit fence with a 150 mm overhang, angled at 45 degrees, successfully excluded all rabbits when a simple 900 mm fence did not (R. Trout pers. comm.).

The propensity for rabbits to dig is often the greatest challenge faced when trying to exclude them from an area; this occurs most frequently where soils are light (Williams et al. 1995). Mesh aprons secured to the ground surface or buried either vertically and/or horizontally are used to deter rabbits from digging under fences. The size of these aprons varies from the recommended 150 – 180 mm (Hay 1999, Lowe 2002) to 300 – 600 mm used by most fence managers spoken to during this review. Rabbits have been found to repeatedly dig under fences at preferred spots, probably where the fence bisects a frequently used route (McKillop *et al*.1998); larger aprons may be required in these areas. McKillop et al. (1998) found no difference in the number of holes rabbits dug under a fence with a 150 mm apron secured to the ground surface compared to an apron that extended 150 mm vertically below the ground and then 150 mm horizontally. Other than this, no research has been conducted to determine the optimal apron size for this species.

Temporary electric mesh fences (80 x 80 mm and 500 x 50 mm mesh sizes) have been trialed in England to protect crops from rabbits and, although the majority of rabbits avoid the fences after receiving a shock, complete exclusion was not achieved (McKillop and Wilson 1999). Strained wire electric fences (100 mm wire spacing) were even less successful, with rabbits learning to push under the bottom wire undeterred by any shock received (McKillop *et al*. 1992). The use of two or more electric wires above a short (200 – 300 mm

Figure 11. A standard, well-maintained rabbit fence at the Royal Botanic Gardens Cranbourne.

high) wire netting fence has been found to be effective in some instances (Casey 1994b) but not in others (Sexton 1984). Interestingly however, rabbits have been shown to avoid digging under electric fences, including those they are unable to push under (McKillop and Wilson 1987, McKillop et al.1992).

8.3 Feral pig behaviour and fencing

Fencing is generally not regarded as the best control technique for feral pigs except for enclosing relatively small, highly valuable areas (McIlroy 1993 cited in Choquenot et al.1996), and hence its use to date is mainly in protecting agricultural crops and stock, particularly lambs (e.g. Tilley 1973, Mitchell et al. 1977, Plant 1980). Since feral pigs are large, robust animals reaching up to 115 kg in size (Choquenot et al.1996), fences must be equally robust to exclude them. If a pig is sufficiently motivated it will eventually breach a fence (D. Choquenot pers. comm.) and therefore it is important to erect exclusion fences before pigs become accustomed to utilising the enclosed food source (Plant 1985).

Pigs are known to pass through plain wire fences, usually between the wires at their snout level (Hone and Atkinson 1983). To prevent this, electrified wires, often on outriggers or attached to stakes to form trip-wires, are commonly used (Mitchell et al. 1977, Choquenot et al. 1996). While this greatly reduces the number of pigs breaching fences (Mitchell et al. 1977, Hone and Atkinson 1983) some pigs react by charging through the fence (Hone and Atkinson 1983). Therefore, it is important that the fence also forms a significant barrier to movement. This can be achieved by using prefabricated fences with small mesh sizes eg. 150 mm vertical wire spacings, (Hone and Atkinson 1983) or wire netting (Casey 1994a, I. McDouall pers. comm). Fences need to be at least 1050 mm high to prevent them being scaled (Tilley 1973). Although pigs will preferentially pass through fences, they will also push under them (Hone and Atkinson 1983) using existing holes or rooting out soft earth beneath the fence if necessary (Fig. 12; Aviss 1994). Consequently, there should be little or no gap between the base of the fence and the ground.

If their construction is sufficiently robust, fences designed to exclude feral cats and foxes should exclude feral pigs at least as successfully as those fences designed to exclude feral pigs alone. These fences may benefit from an offset electric wire at a height of 200 – 400 mm to minimise damage to the fence if feral pigs are particularly problematic.

Because pigs have less hair than most animals, they should be more prone to receiving an electric shock (McCutchan 1980). Trip-wires set at their chest height are designed to deliver a shock to animals that lean forward to investigate the main fence (R. De Silva pers. comm.). Deterring pigs before they reach the main fence should reduce the incidence of them charging forwards through the fence and reduce damage to the fence which can occur if the pig throws its head up and backwards in an attempt to escape (R. DeSilva pers. comm.). The stakes supporting these trip-wires must be firmly driven into the ground and closely spaced to prevent them being uprooted (I. McDouall pers. comm.).

8.4 Feral goat behaviour and fencing

Because feral goats eventually breach most fences, fencing is often regarded as a tactical weapon to facilitate control operations rather than a tool for achieving complete exclusion (Parkes et al. 1996). Fences designed to contain domesticated goats will be inadequate in containing their feral counterparts (Parkes et al.1996, Department of Agriculture, W.A. 2001).

Electric strained wire fences are sometimes recommended but usually for feral goats that are being trained for domestication (Niven and Jordan 1980, Piesse 1995, Kleemann et al. 2003). Untrained feral goats will pass straight through such fences when sufficiently motivated (S. Pratten pers. comm.). Instead, fabricated mesh fences (see p 5–6 of the fence design catalogue) afford a sufficient level of protection against goats pushing through fences (S. Pratten and R. Henzell pers. comm.). The number of horizontal wires in the

Figure 12. Pig damage.
Evidence of damage caused by a feral pig pushing through a chain mesh fox/cat exclusion fence in a boggy area.

fabricated fencing should be maximised to provide an adequate barrier (R. Henzell pers. comm.).

Fabricated fencing with vertical wires spaced at 150 mm have been found to exclude all but the youngest goats (Cash and Able 1994). However, horned goats are known to get their heads stuck in this mesh size, and, consequently, 300 mm vertical wire spacings are recommended (Parkes et al.1996, Kleeman et al. 2003). If feral pigs and/or kangaroos also occur in the area, this 300 mm mesh size may encourage them to push through the fence, necessitating the use of the narrower mesh size (S. Pratten pers. comm.). In the New South Wales Hunter Valley, where all of the above species co-exist, 150 mm fabricated feral goat fences with electric trip wires (see p 5 of the fence design catalogue) have been successfully used on several agricultural properties without any recorded incidence of entangled goats (S. Pratten pers. comm.). We recommend, however, that frequent monitoring of such fences is conducted.

Goats will first attempt to push under or through a fence (Piesse 1985, R. Henzell pers. comm.), therefore it is essential that any gap between the fence and the ground should not exceed 80 mm (Parkes et al.1996, S. Pratten pers. comm.). This may be achieved by extending the wire mesh barrier to ground level. However, to reduce corrosion caused by contact with damp ground or corrosive soils, a single wire (that can easily be replaced) between the ground and mesh is frequently used. The levelling of irregularities in the ground surface will help in minimising the gap below the fence, or, if additional security is required, an apron of wire netting pinned to the ground surface may be used to prevent small goats pushing under the fence (Parkes et al.1996). Electric trip wires have also been successfully used to deter goats (Pratten undated) from pushing under fences. It is believed these are necessary on both sides of the fence to also prevent non-target species creating holes beneath the fence which will later be used by goats (S. Pratten pers. comm.).

Being adept at climbing and jumping, feral goats will readily pass over a fence if presented with the opportunity (R. Henzell pers. comm.). Therefore, external wooden diagonal bracing posts should be avoided (Parkes et al.1996). Instead galvanised pipe angle stays or crossbraces constructed from wire or iron rods are recommended (Parkes et al.1996). Steel pipe strainer posts are also recommended in preference to treated pine posts that provide a platform for goats to jump onto (S. Pratten pers. comm.).

Goat fences that are constructed to a height of 1200 mm will be adequate in most cases although feral goats have been observed jumping fences of this height (R. Henzell pers. comm.). Therefore, if the aim is to achieve complete exclusion, additional protection will be achieved by increasing the fence height. Fences designed to exclude feral goats should also effectively exclude feral goats.

8.5 Dingo/wild dog behaviour and fencing

Dingo exclusion fencing has been used to protect pastoral properties in Australia since the early 1900s (McKnight 1969, Fleming et al. 2001). Traditionally, dingo fences have been constructed of 1800 mm high wire netting (Fleming et al. 2001). Dingoes typically attempt to push through fences, rarely opting to jump over them, at least if they're electrified (Bird 1994), and consequently, cheaper electric fences as low as 900 mm (Bird 1994, Lock 1994, Bird et al. 1997) are beginning to supersede the more expensive taller designs (Fleming et al. 2001).

Multi-stranded electric fence designs have become popular in recent years (Clark and Dunlop 1984, Blinksell 1985, M. Balharry pers. comm.) although they are not universally regarded as effective (Bird et al. 1997, D. Hardman and B. Harden pers. comm.). This variation in attitudes is understandable in light of research conducted on the effectiveness of various electric fence designs that suggested stringent conditions must be met for electric fences to successfully exclude all dingoes (Bird 1994). Bird (1994) reported that a simple seven wire electric fence proved successful in deterring dingoes when the energiser output was adequate, substrates were firm and even, dingoes approached fences slowly, and they had not been previously 'trained' to breach unpowered fences. However, it was found that if any one of these conditions was not met, even a nine-wire electric fence was not able to exclude all dingoes.

The following behavioural responses of dingoes towards electric fences were recorded by Bird (1994):

> Dingoes preferentially push between wires in the middle sections of a fence, typically at heights between 175–600 mm (corresponding approximately to their snout level). Almost all individuals are deterred by wire spacings of 75–100 mm, although occasionally animals are capable of passing through these gaps, usually when the fence is approached at speed. If pushing through the fence proves unsuccessful, dingoes often attempt to push under the fence, undeterred by bottom barbed wires. However, they rarely dig under electric fences unless they have gained experience doing so when the fence was unpowered and they were presented with existing gaps on which to capitalise. Having breached unpowered fences, some individuals

continue to breach powered fences if the energiser output is low. A 4.2 J energiser or larger, delivering at least 2.0 kV, appeared to be an adequate deterrent. However, because dingo fur has good insulating properties, individuals may not receive a shock unless they firmly contact adjacent earth and live wires. Younger animals, such as dispersing subordinates, are more likely to repeatedly challenge a fence, even after sustaining shocks.

It is apparent from this that any fence must form a significant barrier to slow the approach of dingoes and prevent them pushing through it. This may be achieved by very closely spaced electric wires, wire netting or fabricated fencing (Fig. 13; also see p 15–17 of the fence design catalogue). A sloping and composite electric fence (see fence design catalogue p 15–16) trialed by Bird et al. (1997) effectively excluded dingoes from flocks of sheep over an extended period of time (greater than 3.5 years) whereas simple 7 and 8-wire electric fences did not. The sloping and composite designs use very narrow wire spacings or netting in the lower section of the fence where the pressure from dingoes is greatest. While both designs proved equally effective under the conditions, the netting base of the composite design will provide extra protection from dingoes that may approach the fence at speed or attempt to push under the fence (particularly if the substrate is soft or erodes readily). The netting apron will also effectively earth animals standing on it (assuming it is not buried) ensuring they receive a shock from the electric wires.

Based on a study of the size of holes dug by dingoes below fabricated fences, it is thought that a rectangular mesh size of 150 mm wide and 100 mm tall should exclude all dingoes (B. Harden and D. Hardman unpubl. data.). In situations where it is not possible to maintain a consistently small gap (50 mm or less) between the base of the fence and the ground, a wire netting apron is recommended to prevent dingoes pushing under the fence (B. Harden and D. Hardman pers. comm.).

While dingoes seem reluctant to jump electrified fences, it is unknown if the same is true for non-electrified fabricated or netting fences. The jumping behaviour of wild dogs that are of domestic stock is also unknown. Dingoes in captivity are capable of jumping 1500 mm high, and in the wild, a dingo being chased was observed to scramble over a netting fence of this height (P. Bird pers. comm.). In north eastern NSW some landholders are opting to use 1200 mm high fences rather than 1500 mm high fences (see fence design catalogue p 17) that are more expensive and difficult to construct (B. Harden pers. comm.). However, until reliable information suggests otherwise, a minimum fence height of 1500 mm is recommended for fabricated and netting fences (P. Bird pers. comm.). Electric fences need only be constructed to a minimum height of 950 mm.

Fabricated and netting fences form a more significant physical barrier than the electric fences shown in the catalogue, however, the electric fence designs are considerably cheaper and probably only marginally less effective. The choice of design will therefore depend on an assessment of the biodiversity 'cost' of dingo/dog incursions (which will vary according to the conservation value that is being protected).

Photo courtesy of the Queensland Parks and Wildlife Service

Figure 13. A dingo exclusion fence using fabricated fencing.
This fence protects the northern hairy-nosed wombat population in Queensland from dingo predation. Note the cleared track on both sides of the fence that will allow the fence to be easily accessed for monitoring and maintenance purposes.

Table 3. Summary of minimum fencing specifications for each pest species

	Foxes	Feral cats	Feral rabbits	Feral pigs	Feral goats	Dingoes/ Wild dogs
Jump height/ minimum fence height	Capable of jumping at least 1800 mm.	Capable of jumping at least 1800 mm.	Minimum fence height 900 mm – additional protection with higher fence.	Minimum fence height 1050 mm.	Fence height preferably 1200 mm or more.	Minimum height of 900 mm for electric fences and 1500 mm for netting/fabricated fences
Maximum mesh size	Less than 80 mm (and probably less than 70 mm to exclude small animals and juveniles)	50 mm (less for kittens)	30 mm	Fabricated mesh with 150 mm vertical wire spacings preferred.	300 mm fabricated fencing mesh size excludes adult goats[1].	150 mm width and 100 mm height
Maximum gap size below fence	None	None	None	Preferably none, or very minimal	Less than 80 mm	Less than 50 mm
Digging ability	Good	Unknown	Excellent	Excellent	N/A	Good
Climbing ability	Excellent	Excellent	Capable of climbing	N/A	Good	Unknown
Reaction to electrification[2]	Deterred by electric shocks but may learn to avoid these.	Variable response	Electric wires may deter rabbits from digging beneath fences	Variable response	Effectively deter goats if used in conjunction with an effective barrier	Deterred by electric shocks.
Optimal spacing between electric wires	70 – 90 mm when offset from netting fences (preferably at the lower end of the range)	80 mm when offset from netting fences	N/A	Unknown	Unknown	75 – 100 mm or less in middle and lower sections of fence
Other attributes	Chew through plastic mesh		Chew through plastic mesh	Strength, enables pigs to push under and through fences		

1 A 150 mm spacing between vertical wires will probably exclude more juvenile goats however, horned goats are known to get their heads caught in this mesh size and, consequently, a 300 mm wire spacing is recommended.

2 Assuming sufficient contact is made resulting in the animals receiving an electrical shock

9 Non-target animals

Fences designed to exclude feral animals will invariably have some impact on native fauna (e.g. McKillop and Wilson 1987, McKillop and Sibly 1988, Lund and DeSilva 1994). Fences act as barriers, potentially requiring native fauna to alter their normal ranging behaviour and preventing their dispersal into, or out of the enclosed area. This prevents breeding between populations on either side of the fence, essentially creating an isolated population within the enclosed area. It may also cause populations to increase to the point that they exceed the natural carrying capacity of the area. In this circumstance the population may need to be actively managed by the landholder to prevent starvation of the animals and to conserve the habitat. This is most frequently achieved by culling, sterilisation or translocation, which can be costly and often becomes socially and politically controversial. Rather than attempting to achieve such a difficult balancing act, it may therefore be better to create a fence that is semi-permeable to native wildlife. Unfortunately, this is not always possible, and, in some situations not desirable, particularly when dealing with reintroduced threatened fauna.

Native fauna are occasionally injured or killed by exclusion fences either because they collide with the fence, become trapped or entangled in the wires or mesh, or are electrocuted by contacting a live wire and the ground or an earthed section of the fence. All but three respondents in our survey of existing fences reported native fauna being adversely affected in these ways (Table 2 and 4), however in every case this occurred infrequently. Consequently, the overall impact feral exclusion fences have in terms of killing and injuring native fauna is considered to be minimal compared to the benefits expected to be conferred on such fauna by the provision of an environment that is free of feral animals. Greater impacts on native wildlife and their habitat is likely to be caused by the mentioned overpopulation of enclosures by one or more species.

In their encounters with fences, native fauna sometimes damage the fence or undermine its effectiveness. This may necessitate infrequent minor maintenance to the fence, such as fixing an electrical short, through to more time consuming and sometimes ongoing maintenance as is required when kangaroos damage fences or wombats repeatedly dig under them. Therefore, it is important both from an animal welfare viewpoint and from a fence management perspective, to identify those non-target species in the local area that are likely to be adversely affected by the erection of an exclusion fence, and to consider possible design solutions to mitigate interactions between these fauna and the fence (see below).

9.1 Mitigating the threats of fences to native fauna

The majority of incidents that result in the electrocution of native fauna are unpreventable. These incidents typically involve small animals contacting both a live wire and an earthed section of the fence. The behavioural responses of some animals to electric shocks makes them prone to electrocution. Snakes often curl around an electric wire after receiving a shock, as do sugar gliders (*Petaurus breviceps*) with their tails, when they land on the top wire of fences and steady themselves using their tail on the next wire down, whilst Echidnas curl up in a ball after receiving a shock, often remaining in contact with the electric wire (Lund and DeSilva 1994). In some cases altering the wire spacing slightly may decrease the incidence of electrocution (Lund and DeSilva 1994) without compromising the effectiveness of the fence as a barrier to feral animals. For example, ensuring that all electric wires are at least 210 mm from the ground has been found to prevent echidna deaths (D. Hardman pers. comm.).

Snakes and large lizards that become trapped in wire netting tend to do so because their body shape and scales allow them to push partially through the fence but not retract from it (N. Clemann pers. comm.). Large lizards, with their triangular-shaped heads are particularly prone to this. The use of larger wire mesh sizes will permit a wider range of native fauna to pass unhindered through the fence. However, the upper limit of the mesh size will be restricted by the need to prevent the movement of the targeted feral animals (See section 9.6). For example, a 50 mm mesh size would permit the movement of a wider range of fauna and reduce non-target deaths but this mesh size is insufficient to exclude rabbits (K. Moseby, G. Paras pers. comm.). Staff at the Arid Recovery Project found no difference in the deaths of non-target species when the mesh size of their fence was reduced from 40 mm to 30 mm (K. Moseby pers. comm.), however this may vary between sites depending on the complement of species present. Regular monitoring of the fence, particularly during the warmer seasons when reptiles are active, will reduce the proportion of animals that become trapped in the fence dying from dehydration, starvation, heat or cold exposure, or predation.

Tortoises are sometimes found dead or dehydrated along exclusion fences that block their dispersal route. Regular fence inspections during the dispersal season should be conducted to minimise this. tortoises found at the fence line can then be relocated to a nearby pond (within or, if necessary, outside the enclosure) if this is deemed appropriate by the governing conservation agency. This problem can be further alleviated by creating small ponds every 200 m (approximately) near the fence to provide a refuge for dispersing tortoises, a technique used successfully in Western Australia by the Department of Conservation and Land Management (CALM) at sites designed to protect the western swamp tortoise (*Pseudemydura umbrina*) (R. Martyn pers. comm.). Adequate cover must be provided at these pond sites (plantings and/or shadecloth have been used) to protect the tortoises from avian predators. At a site near Perth where oblong tortoises (*Chelodina oblonga*) attempt to disperse between ponds on opposite sides of an exclusion fence, artificial ponds have been created at the fence base and a small gap is left under the water beneath the fence to allow tortoises to pass in and out of the enclosure (R. Martyn pers. comm.). This solution is only feasible if the ponds can be sufficiently maintained because if the gap becomes exposed it will be exploited by feral animals.

Table 4. Native Australian wildlife known to have been injured or killed by feral animal exclusion fences.

This information has been compiled from the surveys of exclusion fences conducted during this review (unless stated otherwise). The 'Frequency' column refers to the percentage of survey respondents (from a total of 20) that indicated the taxa has been affected by their exclusion fence. The exact cause of injuries or deaths that occur as a result of animals being entangled in wire netting are unknown but probably include dehydration, heat exhaustion, cold exposure, predation and wounds inflicted by the netting.

Fauna	Cause of injury/death	Frequency
Spiders	Electrocution	5%
Tortoises	Dehydration or predation (when dispersal to neighbouring waterbodies is prevented).	15%
Snakes	Electrocution and entanglement in wire netting	35%
Goannas	Unknown	10%
Dragons	Entanglement in wire netting	20%
Geckoes	Electrocution	5%
Stumpy-tail and Blue-tongue lizards	Entanglement in wire netting	25%
Frogs	Electrocution	5%
Echidnas	Electrocution	15%
Platypus	Electrocution	5%
Sugar Gliders	Electrocution	N/A*
Pygmy possums	Electrocution	5%
Koalas	Electrocution	5%
Kangaroos	Collision with fence	20%
Flying foxes	Electrocution, collision and entanglement with barbed wire	5%
Small passerines (including blue wrens and pardalotes)	Electrocution or collision with fence	3%
Parrots	Collision with fence	5%
Waders and seabirds	Collision with fence	5%

* reported in Lund and De'Silva 1985

Kangaroos preferentially push under or through fences (McCutchan 1980, Lund and De Silva 1994) but are also capable of jumping fences of considerable height – a 2 m high fence may be necessary to contain them (Wilson (undated) cited in McCutchan 1980). Lower fences (Fig 10; also see p 8–9 of the fence design catalogue), or those with strained wires in the upper sections (Fig 8d) will be more 'permeable' to kangaroos, allowing some dispersal. However, this frequently leads to the breakage of upper wires which can become a minor but on-going maintenance issue.

Kangaroos inadvertently collide with fences, sometimes injuring themselves (and damaging the fence) in the process (Fig.14a). Most fence managers in this review reported that kangaroo collisions declined considerably three to six months after the erection of the fence, by which time the animals had presumably become familiar with its presence. It has been suggested that collisions can be reduced by ensuring that the angles of internal corners are greater than 90 degrees, as mesh viewed at an angle (by kangaroos hopping down the fence line) will be more visible than when viewed from a position perpendicular to it (A. Schmitz pers. comm.). It may also be worth trialing the attachment of highly visible materials to sections of the fence that pass through areas of high kangaroo density, particularly when the fence is newly constructed. This concept has proven effective at reducing the collision rate of woodland grouse (Tetrao tetris, T. urogallus, and Lagopus lagopus) with deer fences in the United Kingdom (Baines and Andrew 2003, R. Trout pers. comm.).

Some kangaroos damage fences by fighting with conspecifics on the opposite side. To minimise damage to the fence, heavy gauge netting such as chain mesh can be used in areas where kangaroos are abundant. A cheaper, frequently used alternative, is to install electric wires, often referred to as 'belly wires', that are offset 200 – 300 mm from the fence at heights ranging from 250 – 700 mm (Fig. 14b). These are designed to

Figure 14. Reducing kangaroo damage.
a) Damage to wire netting caused by kangaroo collisions, and b) 'belly wires' to deter kangaroos from the fence-line. Note the surface-laid apron in 'b' will earth animals standing on it, ensuring they receive a shock from the electric wires.

Figure 15. Wombat gates.
Wombat gates at a) the Royal Botanic Gardens Cranbourne and b) Warrandyte State Park,

train kangaroos to avoid the fence although they are unlikely to reduce fence collisions as these presumably occur because kangaroo do not see the fence. Injuries to kangaroos that become entangled in fences can only be reduced by conducting regular fence inspections so that animals can be disentangled from the fence promptly, or euthanased if necessary.

Wombats are known by some as ‘bulldozers of the bush’ – a title which is particularly befitting when it comes to describing their impact on fences. Wombats will either dig or push through or under a fence (Lund and De Silva 1994) creating holes that can later be used by feral animals. Partly as a consequence of the damage they cause to rabbit exclusion fences, the common wombat was declared vermin in Victoria in 1906, a law that was not abolished until 1984 (Triggs 1988). Wire netting aprons have been found to reduce but not prevent the formation of wombat holes under fences (Marks 1998). The most ‘wombat-friendly’ solution is to install ‘wombat gates’ to allow wombats to pass through a fence (Fig. 15). These gates are top hinged, heavy, swinging gates (approximately 400 mm2) that rely on the strength of wombats to push through whilst excluding weaker feral animals (note that the minimum weight required to exclude foxes is unknown). Because wombats regularly use the same trails and holes in fences, Triggs (1988) reports that they can be trained to use gates installed at these points if other holes are regularly repaired. When this is done, wombats have been found to use gates placed up to 800 m apart rather than making a new hole (Triggs 1988). It is also recommended that a wider than normal mesh apron be used on either side of the gate to deter any digging efforts and focus the wombat’s attention on the gate ((D. Farrar pers. comm.). Gates installed in a predator exclusion fence at the Royal Botanic Gardens Cranbourne, and in a rabbit exclusion fence at Warrandyte State Park, Warrandyte, Victoria, function effectively according to staff (C. Wright and D. Farrar pers. comm.) although no research has been conducted to determine how frequently they are used. In contrast, wombats at the Tidbinbilla Nature Reserve appeared not to use wombat gates (K. Phillips pers. comm.). It seems therefore, that the installation of wombat gates may decrease the incidence of wombats digging under fences if efforts are made to deter them from using old holes or creating new ones, but this may not completely eliminate the problem.

Low electric fences, offset by 300 – 400 mm from the main fence have been found to significantly reduce (by 85 – 97%) the incidence of wombats digging under fences (Lock 1994, Marks 1998). These fences have utilised either two electric wires (100 mm and 200 mm from the ground, 6 – 7.3kV; Marks 1998), or three to four wires (alternating electric wires and earth-wires with the top live wire at 300 mm and 400 mm respectively, voltage unknown; Lock 1994). The latter fence has also successfully deterred kangaroos, emus and dingoes (Lock 1994).

9.2 Keeping native fauna within the enclosed area

Often, exclusion fences serve a dual purpose. Not only are they designed to keep feral animals out, but in many cases they must also keep native fauna in. This is frequently the case when dealing with reintroduced, threatened fauna. Depending on the native fauna in question, this may impose additional design constraints on the fence, particularly in terms of the required mesh size and fence height. For example, fabricated netting fences (see fence design catalogue) and strained wire fences will not contain small native fauna. A wire netting apron fitting to the inside of the fence may be required to prevent the enclosed fauna from pushing or digging beneath the fence and offset electric wires may be required to deter climbing animals.

10 Monitoring for feral animal breaches

While most fences are regularly monitored for signs of damage or feral animal breaches, the enclosed area is less frequently systematically monitored for feral animals (see Table 2). The need for systematic monitoring will vary between sites. Feral animal incursions are likely to be opportunistically detected by vigilant staff (through the identification of scats, tracks or killed prey), at sites that are intensively managed. However, incursions are much less likely to be detected at large sites and at sites that are traversed irregularly by staff. Systematic monitoring is recommended in the latter case, and in the former case if a more accurate assessment of management actions and of the effectiveness of the fence over time is required. Systematic monitoring most frequently takes the form of standardised spotlighting transects, sand plots or track transects (animal prints are monitored in the latter two methods).

To prevent delays in finding and destroying feral animals detected within the enclosed area, a response plan is recommended. The required level of response will vary according to the level of threat the feral species pose to the protected conservation value. For example, the surplus killing behaviour of foxes and dingoes means that a single incursion into an enclosure may spell the demise of a considerable number of threatened native animals (Short et al. 2002), particularly if the feral animal is not rapidly detected.

If feral animals are detected within the enclosure it may be useful to determine if these animals are regularly crossing the fence or are resident within the enclosure (possibly having been fenced-in and gone undetected). At the Royal Botanic Gardens Cranbourne, fox baits containing the biomarker Rhodamine B were laid outside a recently constructed fence, and transects were regularly walked within the reserve to search for fox scats containing the marker, which would indicate fence breaches (Coates and Wright in press). Similar methods may be used elsewhere.

Systematic monitoring will provide a good indication of the fence's effectiveness under local conditions but this effectiveness will not necessarily translate to similar fence designs in other environments. If monitoring of feral animal activity is also conducted outside the fence the effectiveness of the fence under different levels of feral animal pressure can be quantified as feral animal densities fluctuate over time (either naturally or as a result of control operations).

11 Knowledge gaps

Only one of the fences surveyed during this review (Floppy top fence, Arid Recovery Project), and four of the other designs included in the fence catalogue (Fabricated pig fence 1, Hone and Atkinson 1983; capped fence; Karori Sanctuary Trust Inc. 1998, Day and MacGibbon 2002; and the sloping and composite dog fences, Bird et al. 1997) have been experimentally tested, allowing their effectiveness to be quantified. This paucity of experimental testing means that we have a lack of well-documented knowledge about the physical capabilities and behavioural responses of the targeted pest species to various fence components. This is preventing the development of fence designs that are optimal in terms of achieving maximum exclusion of feral animals for minimal cost.

To address this, experimental trials of the various designs are required. The first stage of these trials is best conducted in captivity where the densities of feral animals can be manipulated and animal behaviour easily observed and recorded. Past captive trials of exclusion fences (Hone and Atkinson 1983, Karori Wildlife Sanctuary Trust 1998, Day and MacGibbon 2002, Moseby and Read in prep.) have used relatively small enclosures of a design consistent with the relevant fence, to test the capability of feral animals to escape. Feral animals typically display extreme escape responses, therefore trials conducted in this manner will give a rigorous assessment of the fence's effectiveness. The use of small enclosures is also beneficial in that these can be modified relatively easily in response to feral animals exploiting weaknesses in the design. This will result in the production of an extremely robust design which may be more than adequate for any given field situation. Therefore, designs that prove effective in small enclosures should then be trialed in a situation more closely resembling a field scenario to determine if the design specifications can be 'scaled back' and hence made more economical. For example, during trials of the floppy top fence, electric wires were found to be necessary to contain all feral cats in the trial enclosure, however the same design built without the electric wires has proven equally as effective in the field (Moseby and Read in prep.). Extended trial periods are required to ensure the feral animals are not able to quickly learn to negotiate obstacles that they are initially defeated by.

The following research would address the major knowledge gaps that were identified during the course of this review:

- Determine the optimum physical and/or electrical barrier required to prevent feral cats and foxes scaling fences. To achieve this, fence elements currently used to deter feral cats and foxes from scaling fences (i.e. horizontal mesh overhangs, electric wire overhangs, various arrangements of offset electric wires etc) must first be assessed to determine their effectiveness. The most effective elements should then be used in further trials with modifications made where necessary to further maximise their effectiveness and, if possible, minimise the quantity of materials used, producing optimal, cost-effective designs.
- Identify the optimum number, positioning, spacing and voltage of electric wires required to deter each of the targeted feral species (and combinations of these species). Electric wires are used in a majority of exclusion fences but their use is rarely guided by knowledge of the behavioural responses of the target species. There has been some research investigating the positioning and spacing of electric wires (eg. Bird 1994, Coman and McCutchan 1994, Day and MacGibbon 2002, Moseby and Read in prep.) but more is required to enable a list of basic guidelines to be developed.
- Determine the propensity of dingoes and wild dogs to jump fabricated and netting fences of varying heights to identify an optimal fence height. Wire netting and fabricated fencing is expensive and it would therefore be beneficial to know the minimum fence height required to defeat this species, or at least a majority of individuals.
- Compare the effectiveness of fabricated/netting dog fences with the electrified sloping and composite fence designs (or variations of them). There is substantial variation in cost between these designs but their relative effectiveness has not been determined.
- Determine the optimum apron size required to prevent pest and native species digging beneath fences. While it may be assumed that larger aprons are more effective, the digging behaviour of the species of interest may indicate that aprons that extend beyond a certain distance from the fence represent minimal gains in effectiveness.
- Investigate the effect floodgates and culvert grates and covers have on the movement of aquatic fauna and identify solutions to mitigate problems if this is necessary. Considerable effort is made to ensure that waterway gates form an adequate barrier to feral animals but there has been little investigation of the

impacts these features may have on aquatic fauna. This is only likely to be relevant to the small number of exclusion fences that cross permanent waterbodies.

- Pursue design solutions that will facilitate the dispersal of resident native fauna across fences. This would allow populations within feral-free reserves to become source populations for the broader area if desired.
- Assess whether or not there is a conservation requirement for fences that exclude a broader range of pest species, such as introduced rodents.

12 Conclusion

Exclusion fencing is being used increasingly in Australia to protect areas (or species) of high conservation value from vertebrate pests. This review assesses our current knowledge of the factors that contribute to form an effective feral animal exclusion fence, and highlights gaps in this knowledge.

The effectiveness of a fence can be maximised by ensuring that the design is:

- appropriate for the local environmental conditions,
- appropriate for the behaviour of target and non-target species likely to encounter it
- meticulously constructed and maintained, and that
- feral animal populations are reduced in a buffer zone surrounding it.

It is generally accepted that most fences will not be 100% effective at excluding feral animals 100% of the time (Aviss and Roberts 1994, Coman and McCutchan 1994). In this review, 70% of fence managers felt that their fence was sufficiently effective despite most of them being breached occasionally by feral animals.

Of all the fence designs reviewed, few have been tested. While the remaining fences are monitored to some extent, the general lack of experimental testing makes assessing the costs and benefits of various designs difficult. Consequently, we have little capacity to identify optimal exclusion fence designs, that is, designs that maximise the exclusion of the targeted feral animals for minimal cost. Below is a brief summary of the effectiveness of fences designed to exclude the targeted feral animals:

Feral goats and pigs: Feral goat and pig fences are similar in their design, with the highest level of protection being offered by fabricated fencing used in conjunction with one or two offset electric wires (Hone and Atkinson 1983, Pratten pers. comm.). However it is generally agreed that both of these species, and particularly pigs, will eventually breach most fences (D. Choquenot, R. Henzell pers. comm., McIlroy et al. 1977 cited in Choquenot et al. 1996, Parkes et al. 1996).

Feral rabbits: Feral rabbit fence designs vary little, with a standard 900 mm wire netting fence and apron used most routinely. Captive trials have demonstrated that rabbits are capable of crossing a fence of this height (McKillop et al. 1988, R. Trout pers. comm.), although this is unlikely to happen frequently, and therefore extending the height or adding a small overhang may be warranted if an added level of protection is required.

Wild dogs and dingoes: Dog fences vary considerably in their design and cost. Assuming that dingoes and dogs are not inclined to jump non-electrified fences any more than they are electrified ones (this is unknown), fabricated and netting fences with aprons are likely to afford the highest level of protection because the mesh itself is impenetrable (if correctly maintained!). However, the composite and sloping fence designs represent a considerably cheaper alternative with probably minimal compromise in effectiveness.

Foxes and feral cats: Feral cat and fox fences exhibit substantial design variation. We believe the sloping fox fences discussed would offer a considerably lower level of protection than the taller designs but that they have cost and non-target species advantages, and may provide a sufficient level of exclusion for circumstances where some fox incursions can be tolerated. These designs require further investigation. Of the taller designs, only the floppy-top fence and the capped fence have been developed in conjunction with rigorous experimental testing. Consequently, we have most confidence in recommending these designs. These fences have not been formally tested against foxes, however the superior climbing ability of cats is suggested to pose a reliable test of their effectiveness. Also, the effectiveness of the floppy top fence has been closely monitored in the field and no fox breaches have been detected. The capped design was developed to exclude a wide variety of pest species, including rodents, and this makes it considerably less cost-effective than the floppy-top design if the exclusion of cats, foxes, and rabbits alone is required. Future experimental testing of the remaining feral cat and fox designs may show that some of these fences are as effective as the similarly priced floppy-top fence, reflecting the opinions of fence managers.

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David Armstrong, Senior Ranger, Venus Bay Conservation Park, Department for Environment and Heritage, South Australia.

Michael Balharry, Manager South Australian Dog Fence, South Australian Dog Fence Board, Department of Water, Land and Biodiversity Conservation, South Australia.

Tim Bloomfield, Manager Pest Species, Department of Primary Industries, Victoria.

Keith Calder, Valley Manager, Karori Wildlife Sanctuary, Wellington, New Zealand.

P. Cameron, (organisation details witheld), New South Wales.

David Choquenot, Science Manager, Biodiversity & Ecosystem Processes, Landcare Research, New Zealand.

Nick Clemann, Scientist, Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Victoria.

Adam Cohen, Manager, Calga Springs Sanctuary, New South Wales.

Tim Day, Research and Development Manager , Xcluder. Pest Proof Fencing Company, New Zealand.

Ranjith DeSilva, Former Agricultural Mechanisation Advisory Officer, Department of Agriculture, New South Wales.

David Farrar, Ranger, Kinglake National Park, Parks Victoria, Victoria.

Gary Fitzpatrick, Operations Manager, Cleland Wildlife Park, Department for Environment and Heritage, South Australia.

Garry Gray, Technical Officer, Department of Agriculture, Western Australia.

Bob Harden, Senior Project Officer, Vertebrate Pests, Department of Environment and Conservation, New South Wales.

Don Hardman, Ranger, Northern Tablelands Region, New South Wales National Parks and Wildlife Service, New South Wales.

Robert Henzell, Principal Research Officer, Animal and Plant Control Commission, South Australia.

Alan Horsup, Senior Conservation Officer, Queensland Parks and Wildlife Service, Queensland.

Ian Littleton, Owner/Manager, Clarendon Farms, New South Wales.

Clive Marks, Former Department Head, Vertebrate Pest Research Department, Victorian Institute of Animal Science, Victoria.

Rod Martyn, Senior Nature Conservation Officer, Department of Conservation and Land Management, Western Australia.

John McCutchan, Consultant, Formerly University of Melbourne, Victoria.

Ian McDouall, Property Manager, Queensland.

Katherine Moseby, Scientific Advisor, Arid Recovery, Roxby Downs, South Australia.

George Paras, Head Ranger, Wildlife Reserves, Latrobe University, Victoria.

John Parkes, Science Programme Leader, Landcare Research, New Zealand.

Kevin Phillips, Wildlife Officer, Environment ACT, Australian Capital Territory.

Sam Pratten, Grazier/Managing Director, S.G. Pratten Investments P/L, New South Wales.

Cory Robertson, Rural Product Manger, Onesteel, New South Wales.

Andre Schmitz, National Sanctuaries Manager, Australian Wildlife Conservancy, Western Australia.

Phil Shepherd, General Grounds Manager, The Wildfowl and Wetlands Trust, United Kingdom.

Jeff Short, Principal Research Scientist, CSIRO Sustainable Ecosystems, Western Australia

Colleen Sims, Project Officer – Project Eden, Department of Conservation and Land Management, Western Australia.

Paul Slinger, Habitat Manager, Healesville Sanctuary, Victoria.

Roger Trout, Project Leader, Tree Protection, Forest Research, United Kingdom.

Bruce Turner, Research Support, CSIRO Sustainable Ecosystems, Western Australia.

Leanne Wheaton, Curlew Project Officer, Nature Conservation Working Group, New South Wales

Cassie Wright, Former Ranger, Royal Botanic Gardens Cranbourne, Victoria.

Appendix 1: Fencing managers and pest researchers contacted

Name	Position	Organisation	State
Kevin Phillips	Wildlife Officer, Tidbinbilla Nature Reserve	Environment A.C.T.	A.C.T.
Bill Atkinson	Agricultural Protection Officer	NSW Agriculture	N.S.W.
Jeff Brayshaw	Manager, Recreation Parks & Gardens	Broken Hill City Council	N.S.W.
P. Cameron	witheld	witheld	N.S.W.
Adam Cohen	Manager	Calga Springs Sanctuary	N.S.W.
Ranjith De Silva	Formerly Mechanisation Officer	Department of Agriculture	N.S.W.
Tony Geddes	Landholder	Private	N.S.W.
Bob Harden	Senior Project Officer, Vertebrate Pests	Department of Environment and Conservation	N.S.W.
Don Hardman	Ranger	Parks Service Division, Department of Environment and Conservation	N.S.W.
Peter Jarman	Emeritus Professor	University of New England, Armidale	N.S.W.
Ian Littleton	Owner/Manager	Clarendon Farms	N.S.W.
Ian McDouall	Property Manager	Private	N.S.W.
John O'Donnell	Witheld	Witheld	N.S.W.
Sam Pratten	Grazier/Managing Director	S.G. Pratten Investments P/L	N.S.W.
Catherine Price	Project Officer – Recovery & Threat Abatement Planning	Department of Environment and Conservation	N.S.W.
Cory Robertson	Rural Product Manager	Onesteel Waratah	N.S.W.
Jamie Rockliff	Manager, Scotia Sanctuary	Australian Wildlife Conservancy	N.S.W.
Leanne Wheaton	Curlew Project Officer	Nature Conservation Working Group	N.S.W.
Chris Pavey	Threatened Species Scientist	Parks and Wildlife Service, Department of Infrastructure, Planning and Environment	N.T.
Michael Harper	Executive Administrator	Darling Downs-Moreton Rabbit Board	QLD.
Alan Horsup	Senior Conservation Officer	Queensland Parks and Wildlife Service	QLD.
Peter McCrae	Senior Zoologist	Queensland Parks and Wildlife Service	QLD.
David Armstrong	Senior Ranger, Venus Bay Conservation Park	Department for Environment and Heritage	S.A.
Michael Balharry	Manager South Australian Dog Fence, South Australian Dog Fence Board	Department of Water, Land and Biodiversity Conservation	S.A.
Peter Bird	Dingo Management Officer	Animal and Plant Control Commission	S.A.
Gary Fitzpatrick	Operations Manager	Cleland Wildlife Park, Department for Environment and Heritage	S.A.
Park Fogarty	Assistant Manager, Yookamurra Sanctuary	Australian Wildlife Conservancy	S.A.
Robert Henzell	Principal Research Officer	Animal and Plant Control Commission	S.A.
Chris Holden	Threat Management Ecologist	Science and Conservation Directorate, Department of Environment and Heritage	S.A.
Bruce Jackson	Fencing Consultant	Earth Sanctuaries Ltd.	S.A.
Katherine Moseby	Scientific Advisor	Arid Recovery	S.A.
Ray Ambrose	Director	Dandenong Farm Supplies Pty Ltd	VIC.
Mick Baker	Flora and Fauna Officer	Department of Sustainability and Environment	VIC.
Tim Bloomfield	Manager Pest Species	Department of Primary Industries	VIC.
David Farrar	Ranger, Kinglake National Park	Parks Victoria	VIC.
Peter Frappell	Head, Department of Zoology	Latrobe University	VIC.

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Name	Position	Organisation	State
Rod Hill	Ranger – Grasslands	Parks Victoria	VIC.
Michael Johnston	Research Scientist, Primary Industries Research Victoria	Department of Primary Industries	VIC.
Clive Marks	Former Department Head	Vertebrate Pest Research Department, Victorian Institute of Animal Science	VIC.
John McCutchan	Consultant, Formerly University of Melbourne		VIC.
George Paras	Head Ranger, Wildlife Reserves	Latrobe University	VIC
Ray 'Whimpey' Reichelt	Owner/Manager	Little Desert Nature Lodge	VIC.
Paul Slinger	Habitat Manager	Healesville Sanctuary	VIC.
John Turnbull	Regional Wild Dog Program Co-ordinator	Department of Primary Industries	VIC.
Cassie Wright	Former Ranger	Royal Botanic Gardens Cranbourne	VIC.
Rod Martyn	Senior Nature Conservation Officer	Department of Conservation and Land Management	W.A.
Garry Gray	Technical Officer	Department of Agriculture	W.A.
Andre Schmitz	National Sanctuaries Manager	Australian Wildlife Conservancy	W.A.
Colleen Sims	Project Officer – Project Eden	Department of Conservation and Land Management	W.A.
Bruce Turner	Research Support	CSIRO Sustainable Ecosystems	W.A.
Keith Calder	Valley Manager	Karori Wildlife Sanctuary, Wellington	N.Z.
David Choquenot	Science Manager, Biodiversity & Ecosystem Processes	Landcare Research	N.Z.
Tim Day	Research and Development Manager	Xcluder™ Pest Proof Fencing Company	N.Z.
John Parkes	Science Programme Leader	Landcare Research	N.Z.
Phil Shepherd	General Grounds Manager	The Wildfowl and Wetlands Trust	U. K.
Roger Trout	Project Leader, Tree Protection	Forest Research	U. K.

Appendix 2: Species threatened either by foxes, feral cats, feral rabbits, feral goats, feral pigs or feral dogs/dingoes

The following species are listed as threatened under the EPBC Act 1999 and are considered, by The Department of the Environment and Heritage, to be threatened by at least one of the feral animals discussed in this review. A '4' indicates those states and territories in which the species is found (note that 'NI' is Norfolk Island). The 'Status' column displays the national threatened classification of the species (CE = critically endangered, E = endangered, V = vulnerable). The letters in the 'Threat' column indicate those feral species that pose a threat to listed native species (C = feral cat, D = feral dog/dingo, F = European red fox, G = feral goat, P = feral pig, , R = feral rabbit – note that because no threat abatement plan has been written for feral dogs/dingoes, the list of species threatened by this taxa is not considered to be comprehensive).

Species Name	Common Name	Vic	Tas	ACT	Qld	NSW	NT	SA	WA	NI	Status	Threat
Invertebrates												
Engaeus martingener	Furneaux burrowing crayfish		✔								E	FP
Paralucia spinifera	Copper butterfly, purple					✔					V	GP
Fish												
Maccullochella macquariensis	Trout Cod			✔		✔					E	R
Scaturiginichthys vermeilipinnis	Red-finned Blue-eye				✔						E	P
Frogs												
Geocrinia alba	White-bellied Frog								✔		E	P
Geocrinia vitellina	Orange-bellied Frog								✔		V	P
Heleioporus australiacus	Giant Burrowing Frog	✔				✔					V	CF
Mixophyes fleayi	Fleay's Frog				✔	✔					E	P
Mixophyes iteratus	Southern barred frog				✔	✔					E	P
Philoria frosti	Baw Baw Frog	✔									E	CDFR
Pseudophryne corroboree	Southern Corroboree Frog					✔					E	P
Pseudophryne pengilleyi	Northern Corroboree Frog			✔		✔					E	P
Spicospina flammocaerulea	Sunset Frog								✔		E	P
Taudactylus pleione	Kroombit Tinker Frog				✔						V	P
Taudactylus rheophilus	Tinkling Frog			✔							E	P
Litoria aurea	Green and Golden Bell Frog	✔		✔		✔					V	CF
Litoria lorica	Armoured Mistfrog				✔						E	P
Litoria nannotis	Waterfall Frog				✔						E	P
Litoria nyakalensis	Mountain Mistfrog				✔						E	P
Litoria rheocola	Common Mistfrog				✔						E	P
Nyctimystes dayi	Lace-eyed Tree Frog				✔						E	P
Reptiles												
Caretta caretta	Loggerhead Turtle				✔		✔		✔		E	DFP
Chelonia mydas	Green Turtle				✔		✔		✔		V	F
Eretmochelys imbricata	Hawkesbill Turtle				✔		✔		✔		V	P
Natator depressus	Flatback Turtle				✔		✔		✔		V	P
Dermochelys coriacea	Leathery Turtle				✔	✔			✔		V	F
Elusor macrurus	Mary River tortoise				✔						E	F
Pseudemydura umbrina	Western Swamp tortoise								✔		E	F
Delma impar	Striped Legless Lizard	✔				✔		✔			V	CF
Tympanocryptis pinguicolla	Grassland Earless Dragon	✔		✔	✔	✔					E	R
Eulamprus leuraensis	Mountain Water Skink					✔					E	C
Eulamprus tympanum marnieae	Corangamite Water Skink	✔									E	CFR
Mammals												
Dasycercus cristicauda	Mulgara						✔	✔	✔		V	CFR
Dasyuroides byrnei	Kowari				✔			✔			V	CFR
Dasycercus hillieri	Ampurta				✔			✔	✔		E	CFR
Dasyurus geoffroii	Western Quoll								✔		V	CFR
Dasyurus maculatus gracilis	Spotted-tailed Quoll or Yarri	✔	✔	✔	✔	✔		✔			E	CDF
Parantechinus apicalis	Dibbler								✔		E	CF
Phascogale calura	Red-tailed Phascogale								✔		E	CF
Sminthopsis aitkeni kangaroo	Island Dunnart							✔			E	C
Sminthopsis douglasi	Julia Creek Dunnart				✔						E	CF
Sminthopsis psammophila	Sandhill Dunnart						✔	✔	✔		E	F

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Species Name	Common Name	Vic	Tas	ACT	Qld	NSW	NT	SA	WA	NI	Status	Threat
Myrmecobius fasciatus	Numbat								✔		V	CF
Isoodon auratus	Golden Bandicoot						✔		✔		V	CD
Perameles bouganville bouganville	Western Barred Bandicoot								✔		E	CF
Perameles gunnii gunnii	Eastern Barred Bandicoot (TAS)		✔								V	C
Perameles gunnii unnamed sub sp	Eastern Barred Bandicoot	✔									E	CDFR
Macrotis lagotis	Greater Bilby				✔	✔	✔		✔		V	CDFR
Lasiorhinus krefftii	Northern Hairy-nosed wombat				✔						E	CP
Burramys parvus	Mountain Pygmy-possum	✔				✔					E	CFR
Petaurus gracilis	Mahogany Glider				✔						E	C
Bettongia lesueur	Burrowing Bettong								✔		V	CFR
Bettongia tropica	Northern Bettong				✔						E	DFP
Potorous longipes	Long-footed Potoroo	✔				✔					E	CDFP
Potorous tridactylus gilberti	Gilbert's Potoroo								✔		E	CF
Lagorchestes fasciatus	Banded Hare-wallaby								✔		V	CF
Lagorchestes hirsutus	Rufous Hare-wallaby								✔		E	CFR
Onychogalea fraenata	Bridled Nailtail Wallaby				✔						E	CFR
Petrogale lateralis (Macdonnell Ranges)	Black-footed Rock-wallaby						✔	✔			V	CFG
Petrogale lateralis (West Kimberley)	Black-footed Rock-wallaby								✔		V	
Petrogale penicillata	Brush-tailed Rock-wallaby	✔									V	CFGR
Petrogale persephone	Proserpine Rock-wallaby				✔						E	CD
Petrogale xanthopus	Yellow-footed rock wallaby				✔	✔		✔			V	G
Notoryctes caurinus	Northern Marsupial Mole								✔		E	CF
Notoryctes typhlops	Southern Marsupial Mole						✔	✔	✔		E	CF
Hipposideros semoni	Semon's Leaf-nosed Bat				✔						E	C
Rhinolophus philippinensis	Greater Large-eared Bat				✔						E	C
Leporillus conditor	Greater Stick-nest Rat							✔	✔		V	CDF
Pseudomys fieldi	Djoongari								✔		V	CFGR
Pseudomys fumeus	Smoky Mouse	✔				✔					E	CF
Pseudomys oralis	Hastings River Mouse				✔	✔					E	CF
Zyzomys pedunculatus	Central Rock-rat							✔			E	CFP
Crocidura tenuata var. *trichura*	Christmas Island Shrew								✔		E	CD
Birds												
Casuarius casuarius johnsonii	Southern Cassowary				✔						E	P
Diomedea exulans	Wandering Albatross	✔	✔			✔		✔	✔		V	CR
Thalassarche chrysostoma	Grey-headed Albatross		✔								E	CR
Macronectes giganteus	Southern Giant-Petrel	✔									E	CR
Macronectes halli	Northern Giant-Petrel	✔									E	R
Pterodroma leucoptera leucoptera	Gould's Petrel	✔	✔		✔	✔		✔			E	R
Leipoa ocellata	Malleefowl	✔		✔		✔		✔	✔		V	CDFGR
Turnix melanogaster	Black-breasted Button-quail				✔	✔					V	CFP
Calyptorhynchus lathami halmaturinus	Glossy Black Cockatoo							✔			E	GR
Pezoporus wallicus flaviventris	Western Ground Parrot								✔		E	CF
Geopsittacus (Pezoporus) occidentalis	Night Parrot	✔			✔	✔	✔	✔	✔		E	CFR
Lathamus discolor	Swift Parrot		✔	✔	✔		✔		✔			E C
Neophema chrysogaster	Orange-bellied Parrot	✔	✔					✔			E	CFR
Cyanoramphus novaezelandiae cookii	Norfolk Island Parrot									✔	E	C
Ninox novaeseelandiae undulata	Norfolk Island Boobook Owl									✔	E	C
Stipiturus malachurus intermedius	Southern Emu-wren	✔									E	CF
Amytornis textilis modestus	Thick-billed Grasswren (eastern)						✔	✔			V	R
Amytornis textilis myall	Thick-billed Grasswren (Gawler Ranges)							✔			V	R
Amytornis textilis textilis	Thick-billed Grasswren (western)								✔		V	CFGR

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Species Name	Common Name	Vic	Tas	ACT	Qld	NSW	NT	SA	WA	NI	Status	Threat
Acanthiza iredalei iredalei	Slender-billed Thornbill							✔	✔		V	R
Dasyornis brachypterus	Eastern Bristlebird	✔			✔	✔					E	CFP
Pardalotus quadragintus	Forty-spotted Pardalote		✔								E	C
Climbers												
Cynanchum elegans	White Cynanchum					✔					E	GPR
Herbs												
Ballantinia antipoda	Southern Shepherd's Purse	✔									E	PR
Borya mirabilis	Grampians Pincushion-lily	✔									E	GR
Brachyscome muelleri								✔			E	G
Conostylis micrantha	Small Flowered Conostylis								✔		E	R
Cullen parvum	Small scurf-pea	✔				✔		✔			E	P
Eriocaulon carsonii	Salt Pipewort				✔	✔		✔			E	GP
Patersonia spirafolia	Spiral-leaved Patersonia								✔		E	R
Thesium australe	Austral Toad Flax	✔		✔	✔	✔					V	R
Orchids												
Burmannnia sp (Melville Island)							✔				E	P
Phaius australis	Lesser Swamp Orchid				✔	✔					E	P
Phaius tankervilleae	Greater Swamp Orchid				✔	✔					E	P
Pterostylis basaltica	Basalt Greenhood	✔									E	R
Pterostylis despectans	Lowly Greenhood	✔						✔			E	R
Pterostylis gibbosa	Illawarra Greenhood Orchid					✔					E	R
Pterostylis sp. Halbury	Halbury Greenhood							✔			E	R
Pterostylis sp. Northampton	Northhampton Midget Greenhood Orchid					✔		✔			E	PR
Caladenia amoena	Charming Spider Orchid	✔									E	R
Caladenia bryceana bryceana	Dwarf Spider Orchid								✔		E	R
Caladenia busselliana	Bussell's Spider Orchid								✔		E	R
Caladenia caudata	Tailed Spider Orchid		✔								V	R
Caladenia elegans	Elegant Spider Orchid								✔		E	PR
Caladenia formosa	Blood-red Spider Orchid	✔						✔			V	R
Caladenia gladiolata	Bayonet Spider Orchid							✔			E	R
Caladenia hastata	Melblom's Spider Orchid	✔									E	R
Caladenia hoffmanii subsp *graniticola*									✔		E	R
Caladenia lowanensis	Wimmera Spider Orchid	✔									E	R
Caladenia rigida	Stiff White Spider Orchid							✔			E	R
Caladenia robinsonii	Frankston Spider Orchid	✔									E	R
Caladenia rosella	Little Pink Spider Orchid	✔									E	R
Caladenia tensa	Rigid Spider Orchid	✔									E	R
Caladenia thysanochila	Fringed Spider Orchid	✔									E	R
Caladenia vericolor	Candy Spider Orchid	✔									V	R
Caladenia viridescens	Dunsborough Spider Orchid								✔		E	R
Caladenia winfieldii									✔		E	P
Caladenia xanthochila	Yellow-Lip Spider Orchid	✔									E	R
Thelymitra epipactoides	Metallic Sun Orchid	✔									E	R
Thelymitra mackibbinii	Brilliant Sun Orchid	✔									E	R
Thelymitra manginii	Cinnamon Sun Orchid								✔		E	P
Drakonorchis drakeoides									✔		E	G
Shrubs												
Prostanthera eurybioides	Monarto Mintbush							✔			E	R
Acacia araneosa	Spidery Wattle							✔			V	G
Acacia cretacea	Chalky Wattle							✔			E	R
Acacia insolita subsp. *recurva*	Yornaring Wattle								✔		E	R
Acacia rhamphophylla	Kundip Wattle								✔		E	R
Banksia cuneata	Matchstick Banksia								✔		E	R
Chamelaucium sp. *Gingin*	Gingin Wax								✔		E	R
Darwinia carnea	Mongumber Bell	✔		✔							E	R
Daviesia bursarioides	Three Spring Daviesia								✔		E	R
Eremophila nivea	Silky Eremophila					✔			✔		E	R

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Species Name	Common Name	Vic	Tas	ACT	Qld	NSW	NT	SA	WA	NI	Status	Threat
Eremophila viscida	Vanish Bush					✔			✔		E	R
Grevillea althoferorum									✔		E	FR
Grevillea beadleana	Beadle's Grevillea					✔					E	G
Grevillea floripendula	Drooping Grevillea	✔									V	G
Grevillea iaspicula	Wee Jasper Grevillea			✔		✔					E	G
Grevillea maccutcheonii	MacCutcheon's Grevillea								✔		E	R
Grevillea scapigera	Corrigin Grevillea								✔		E	R
Hemiandra gardneri	Red Snake Bush								✔		E	R
Hemiandra rutilans	Sargent's Snake Bush								✔		E	R
Rulingia sp. *Trigwell Bridge*	Trigwell's Rulingia								✔		E	R
Synaphea quartzitica	Quartz-loving Synaphea								✔		E	R
Tetratheca deltoidea	Granite Tetratheca								✔		E	R
Tetratheca gunnii	Shy Susan		✔								CE	R
Verticordia fimbrilepis subsp. *fimbrilepis*	Shy Feather Flower								✔		E	R
Verticordia spicata subsp. *squamosa*	Scaley-leaved Featherflower								✔		E	R
Westringia crassifolia	Whipstick Westringia	✔									E	GR
Trees												
Eucalyptus rhodantha	Rose Mallee								✔		E	R
Ptychosperma bleeseri							✔				E	P

Appendix 3: Survey questionnaire

Twenty feral animal exclusion fences were surveyed during the course of this review. The questions in the survey form below were asked of fence managers at these sites. A summary of the survey results that are likely to be of most interest to the reader are provided in section 5 of the report. The remaining information was used to help determine the effectiveness of the various fence designs and used as a basis for many of the recommendations in this report.

Where and Why?

When was the fence built?
What is the length of the fence?
What size area does the fence enclose?
What conservation values was the fence built to protect?
Which feral animals is the fence specifically designed to exclude? What other feral animals does the fence exclude? Are these also considered to be a threat to the primary conservation value being protected?
Describe the substrate, general topography and vegetation communities the fence passes through:

Fence design and specifications

Was any research conducted prior to the construction of the fence to determine the design? If so can you provide details of this?
Fence Height:
Materials used Wire/Mesh size and type: Strainer posts: Intermediate posts: Post spacing: Outriggers: Insulators:
Apron Dimensions: Materials:
Does the fence have an overhang? Dimensions: Angle: Support structures:
Number of electrified wires? Location on fence: Voltage: Pulse rate: Power source:
What is the design of the access gates into the enclosed area?

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Does the fence cross any streams or drains? If so, what design features have been incorporated into the fence at these points.
Do the above mentioned design features function effectively?
Are there any other special features that have been incorporated into the fence design to overcome environmental, topographic or human access issues? If so how were these remedied and do these still cause problems?
What was the cost of the fence per kilometre?

Fence maintenance

How regularly is the fence checked for incursions and damage?
Is this believed to be adequate? If not, how often would you ideally like it to be checked?
What are the major maintenance requirements of the fence?
How frequently does the fence require major upgrades?
What would the annual cost of maintenance be in staff hours/days and material costs?
What is the anticipated life of the fence?

Fence effectiveness

Do you believe the fence is effective at excluding the target feral animals?
Is the effectiveness of the fence monitored? If so how?
Can you provide the results of this monitoring?
Have these results lead to any modifications in the fence design?
Is there a system for alerting fence-managers to breaches of the fence?
How do you respond to breaches?
What species breach the fence (both target and non-target species)?
What materials do you used to fill holes dug under fences? Is this effective?
Do you conduct buffer zone control programs? If so can you describe this and do you have any evidence to suggest the fence would be less effective without the buffer zone management?
Do you conduct vegetation clearing around the fence?
What do you perceive to be the major weaknesses in the fence and have you managed to modify the fence to overcome this these?
If money was not a factor, are there any fence design modifications that you believe would greatly enhance the effectiveness of the fence?

Non-target impacts

Do you have any evidence that the ranging behaviour or dispersal of non-target species been adversely affected by the fence?
Have any animals become injured or killed due to presence of the fence?
If so, can you recommend any fence design modifications to prevent this occurring again?